Atmospheric Dynamics III

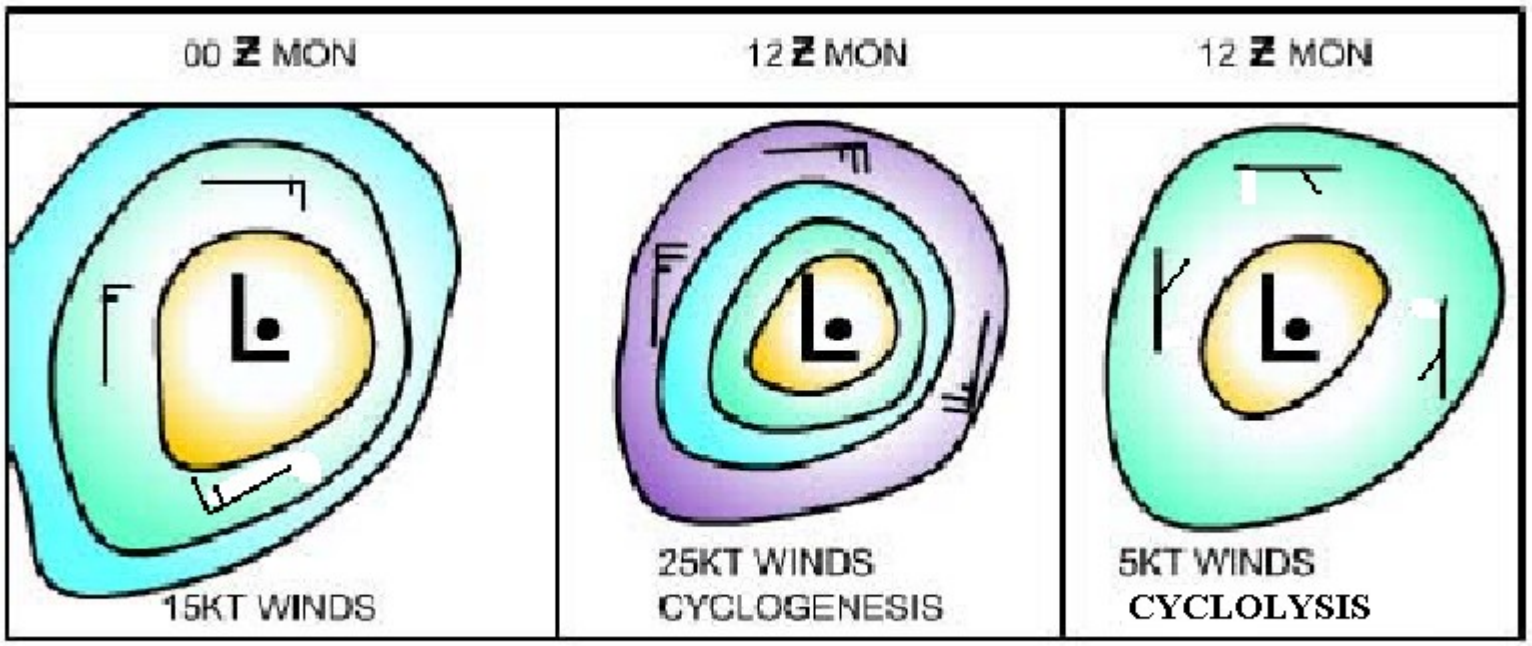
Determine the resulting evolution of the synoptic-scale mid-latitude system indicated.

System Strength Terminology

Various methods can be used to track intensity of pressure systems

- ***Circulation intensity*** is a measure of the strength of wind flow around a system
  - Lows - the stronger the cyclonic flow, the more intense the low is
    - Cyclogenesis - development of cyclonic circulation or intensification of existing cyclonic circulation
    - Cyclolysis - disappearance or weakening of cyclonic circulation

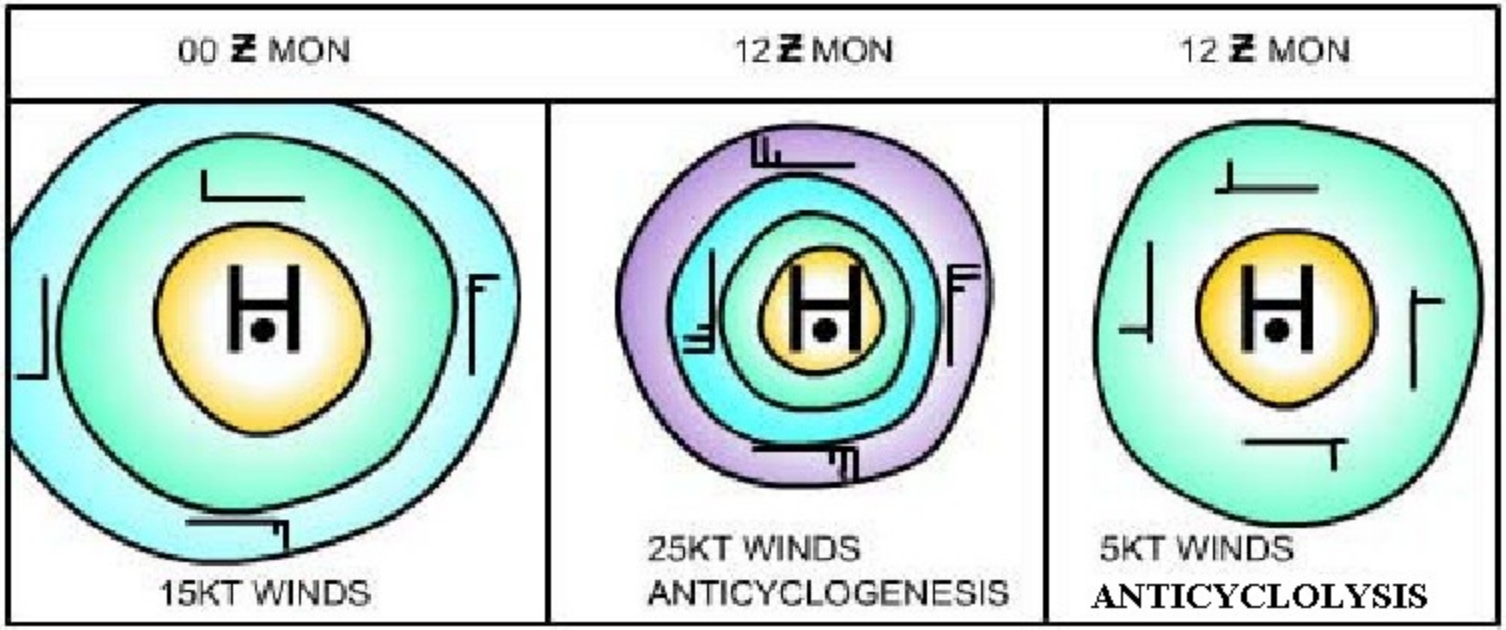
Cyclogenesis and Cyclolysis



System Strength Terminology

- Highs - the stronger the anticyclonic flow, the more intense the high is
  - Anticyclogenesis - development of anticyclonic circulation or intensification of existing circulation
  - Anticyclolysis - weakening or disappearance of anticyclonic circulation

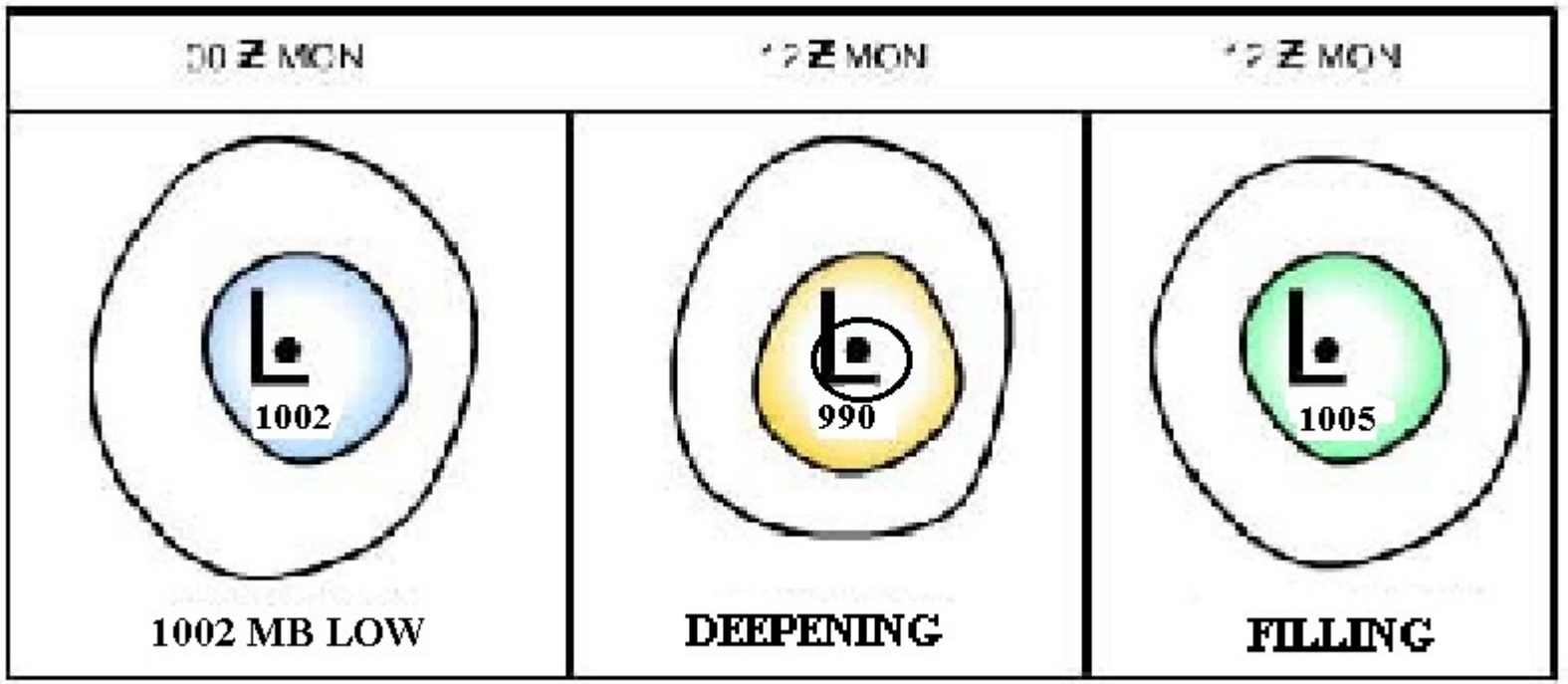
Anticyclogenesis and Anticyclolysis



System Strength Terminology

- Central pressure/height
  - Lows - the lower the central pressure/height, the stronger the system is
    - Deepening - decrease in central pressure/height
    - Filling - increase in central pressure/height

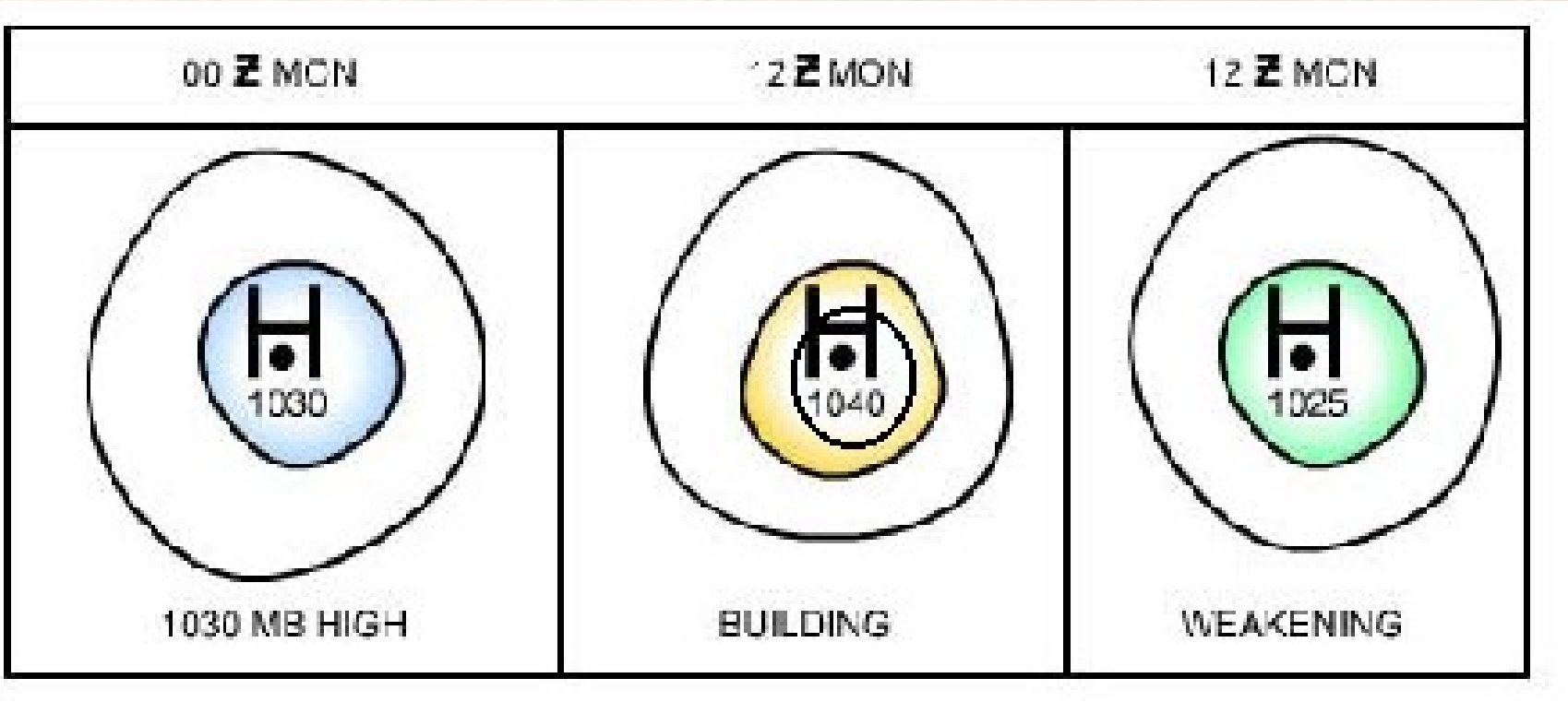
Deepening and Filling



System Strength Terminology

- Highs - the higher the central pressure/height, the stronger the system is
  - Building - increase in central pressure/height
  - Weakening - decrease in central pressure/height

Building and Weakening



System Strength Terminology

- Circulation intensity/central pressure USUALLY changes in a similar manner

- Circulation intensity/central pressure CAN change in "opposite" directions

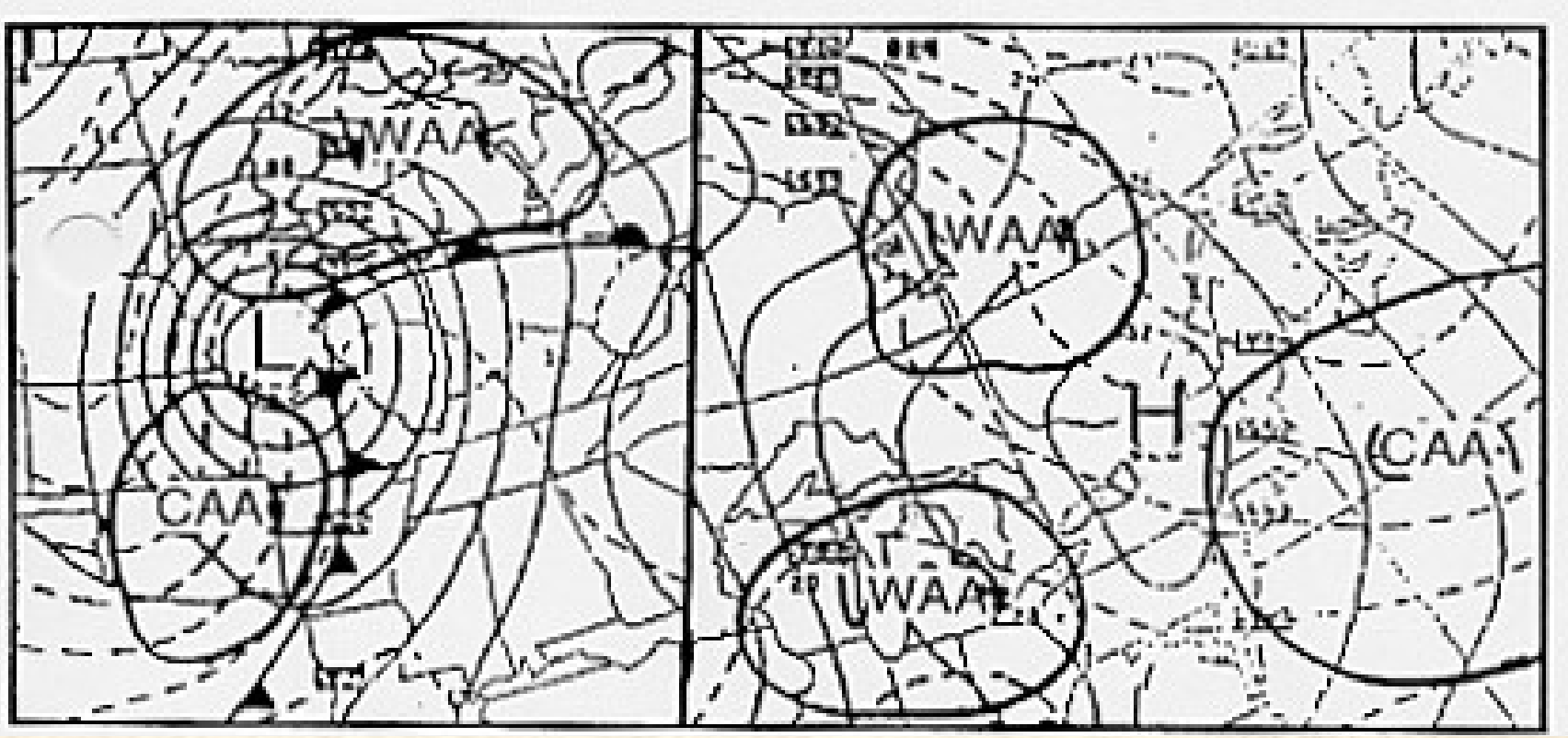
Physical Processes Affecting the Development of Pressure Systems (Petterssen, 1956)

- Thermal Advection
  - Asymmetrical around baroclinic systems
    - Baroclinic lows
      - WAA causes surface pressure falls
      - CAA causes surface pressure rises
      - Weak thermal advection occurs at center of low

Physical Processes Affecting the Development of Pressure Systems

- Baroclinic highs
  - CAA causes surface pressure rises
  - WAA causes surface pressure falls
  - Weak thermal advection occurs at center of high

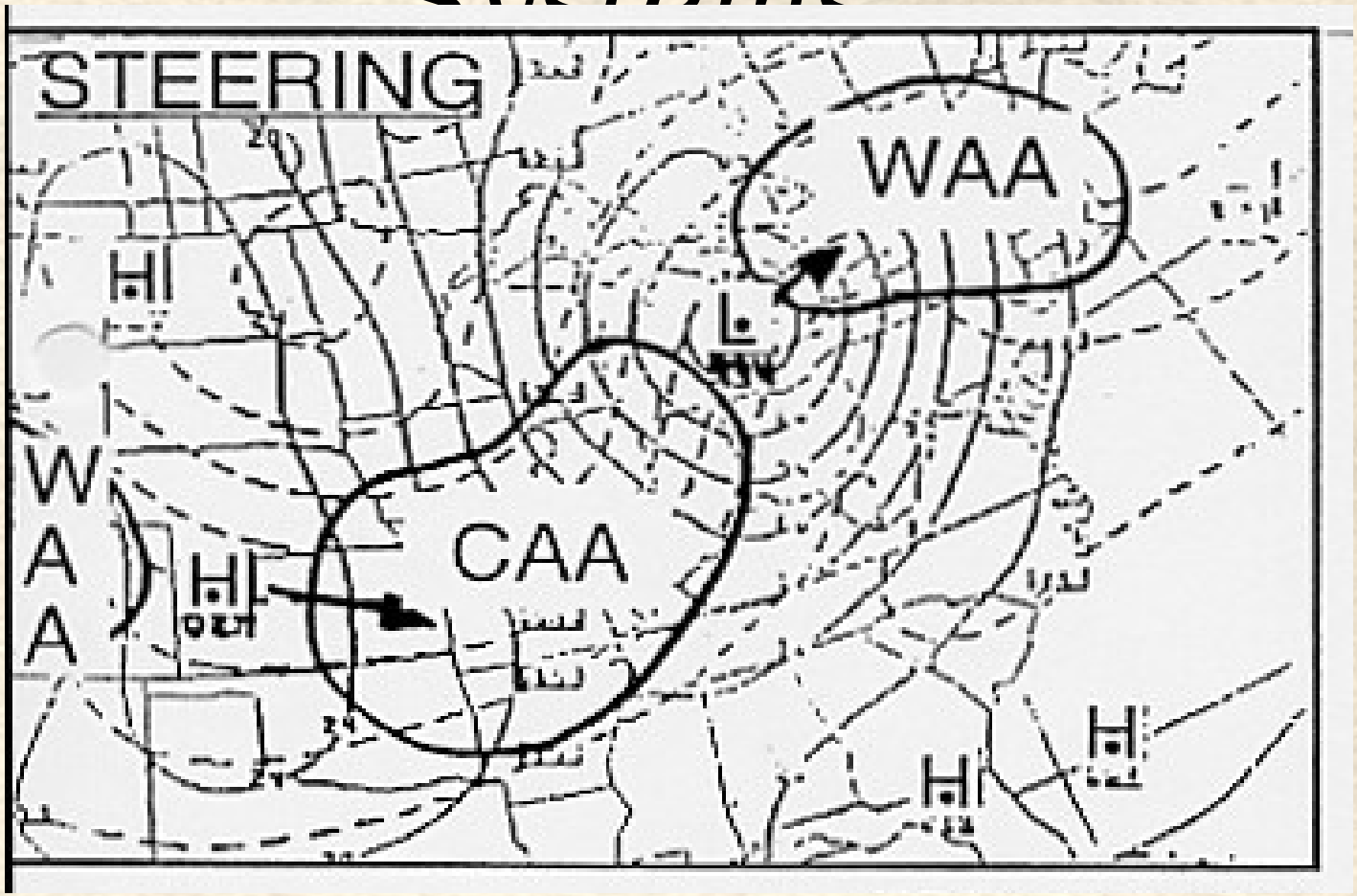
Thermal Advection around a Baroclinic High and Low



Physical Processes Affecting the Development of Pressure Systems

- Weak thermal advection in center cannot significantly change central pressure, except when system begins developing
- It is critically important to upper-level systems
- Influences steering of baroclinic systems
  - Surface lows move toward region of strong WAA
  - Surface highs move toward region of strong CAA

Thermal Advection Steering Baroclinic Systems



Physical Processes Affecting the Development of Pressure Systems

- Vorticity Advection
  - Divergence aloft
    - Indicated by PVA aloft
    - Low level convergence
    - Increase in cyclonic vorticity at the surface
    - Deepens surface lows
    - Weakens surface highs

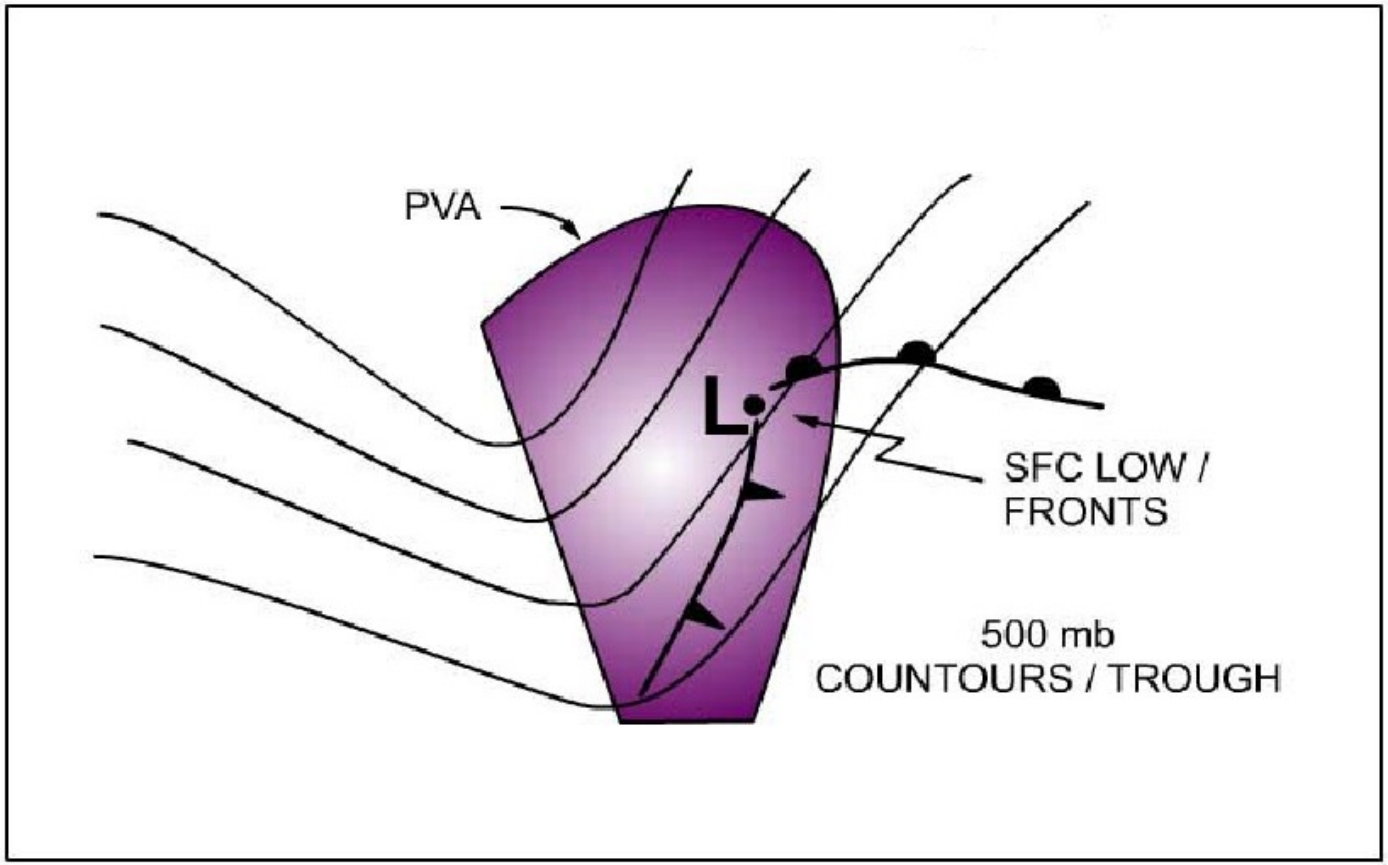
Physical Processes Affecting the Development of Pressure Systems

- Convergence aloft
  - Indicated by NVA aloft
  - Low level divergence
  - Increase in anticyclonic vorticity at the surface
  - Fills surface lows
  - Builds surface highs

Physical Processes Affecting the Development of Pressure Systems

– Well-developed high/low are found under PFJ due to strongest divergence/convergence

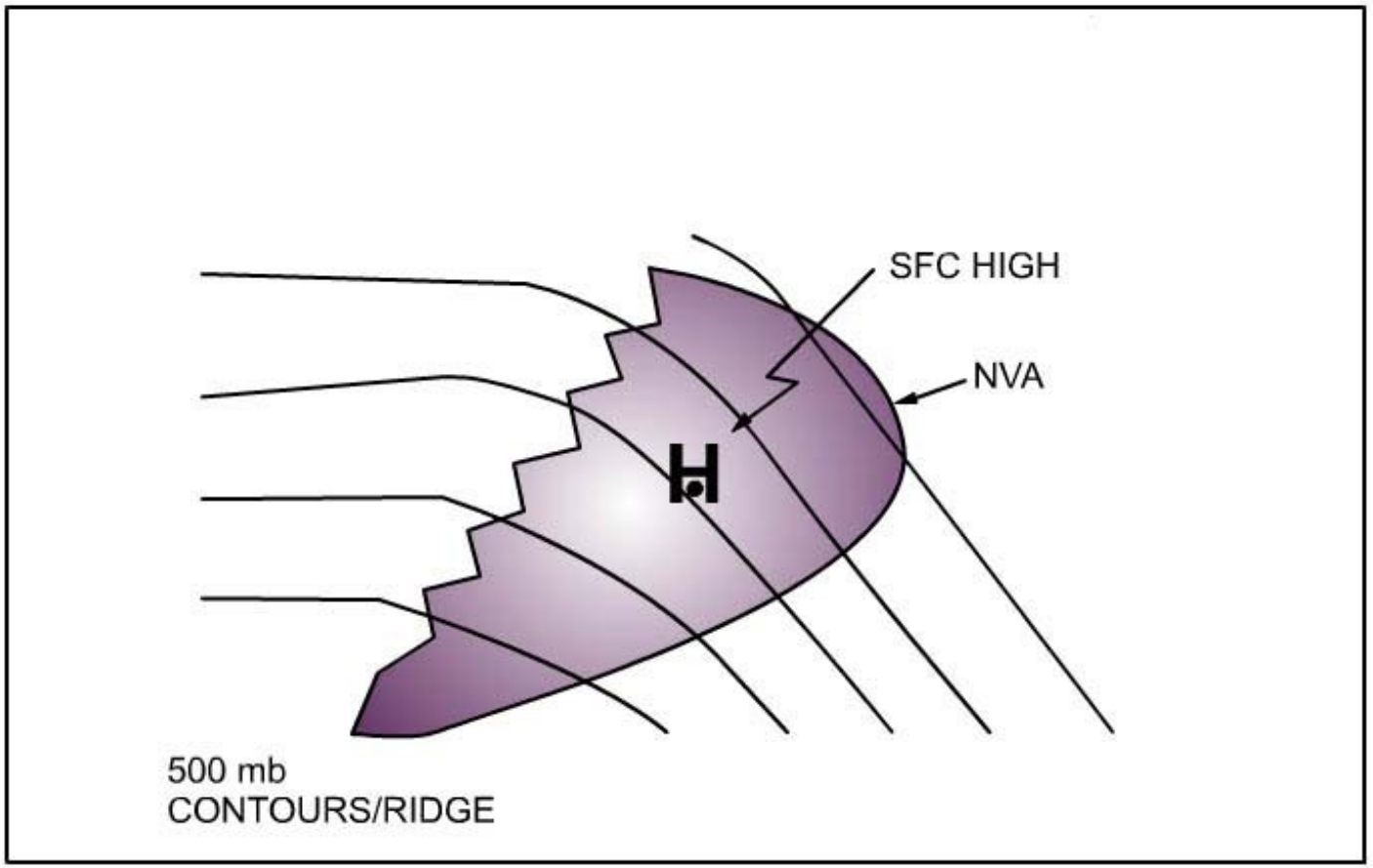
Stack of a Baroclinic Low



Physical Processes Affecting the Development of Pressure Systems

- Baroclinic low tilt with height
  - Linked to major short-wave trough
  - Found within area of divergence
  - Divergence deepens surface low

Stack of a Baroclinic High



Physical Processes Affecting the Development of Pressure Systems

– Baroclinic highs tilt with height

- Linked to major short-wave ridge
- Found within area of convergence
- Convergence builds surface high

Physical Processes Affecting the Development of Pressure Systems

- Adiabatic Processes (i.e., vertical motion processes)
  - The adiabatic lifting (ascent) of air may promote a net cooling or a net warming, depending on the stability of the warm air mass.

Physical Processes Affecting the Development of Pressure Systems

- Generally, ascent is_
  - Found ahead of lows
  - Found behind highs

- Affects development of baroclinic lows only

Physical Processes Affecting the Development of Pressure Systems

- Generally, the air being lifted on the “synoptic scale” is stable. Stable air must be forced to move vertically, but how much “forcing” is require to lift the air depends on the amount of stability and moisture in the air.
  - Energy must be taken from developing system and used to lift stable air

Physical Processes Affecting the Development of Pressure Systems

- Stable, dry (unsaturated) air, with lifted condensation levels (LCLs) at high altitudes, greatly slows development of baroclinic lows
  - Upon lifting, stable dry air becomes much colder than the surrounding environmental air, contributing to a local reduction in the 1000-500 mb thickness.
  - It takes energy away from low development (i.e., retards cyclogenesis) to lift the dry, stable air parcel
  - It is a significant drain on the cyclogenetic process; significant development not likely or a cyclone may not form at all.

Physical Processes Affecting the Development of Pressure Systems

- Stable, moist (saturated) air slows development, but not as greatly
  - Upon lifting, stable moist air does not cool as fast as stable dry air. Thus, there is less energy expended in forcing this air to rise.
  - The atmosphere expends some energy, but the fact the condensation readily occurs upon lifting (i.e., the LCL is at a low altitude) allows latent heat of condensation to partially off-set cooling, and more energy is available to aid cyclogenesis than with dry air. The net effect: Some energy is removed from the cyclogenetic process, but partially returned due to latent heat of condensation
  - It is less of a drain on system development, and more energy is available for development

Physical Processes Affecting the Development of Pressure Systems

- Conditionally unstable air affects system differently depending on whether it is forced to rise or sink
- Conditionally unstable air associated with low is forced to rise. Conditional instability means that, upon lifting, saturated parcels may eventually become unstable.
  - Air must be lifted to LFC (level of free convection). In a conditionally-unstable environment, the LFC only exists for saturated parcels; LFCs do not exist for unsaturated parcels.
  - Then the saturated parcel rises on its own due to positive buoyancy; latent heat of condensation released
  - The parcel becomes warmer than the environment and contributes to a local increase in the 1000-500 mb thickness.
  - The local increase in thickness means that more energy is added than is taken, and this favors further development

Physical Processes Affecting the Development of Pressure Systems

- Stable or conditionally unstable air associated with a high is forced to sink
  - Mean-layer warming, due to air subsiding dry- adiabatically, causes a local increase in thickness as the sinking air becomes warmer than the surrounding environment.
  - The increase in thickness due to adiabatic warming of the sinking air retards anticyclogenesis. Thus, energy is taken from a developing high and limits the strength baroclinic highs can attain

Physical Processes Affecting the Development of Pressure Systems

- Diabatic Effects
  - This process involves the transfer of heat (energy) between air parcel and surrounding environment
  - This transfer is important between the earth's surface and the atmosphere
  - DIFFERENTIAL heating or cooling of air at a given location with respect to surrounding regions causes development

Physical Processes Affecting the Development of Pressure Systems

- Air over warmer surface is heated from below, causing cyclonic development
  - Forcing mechanism for heat low is associated with cT air masses
  - It is a secondary effect for baroclinic lows

Physical Processes Affecting the Development of Pressure Systems

- Air over a colder surface is cooled from below, causing anticyclonic development
  - Forcing mechanism for cold equivalent barotropic high associated with cP air masses
  - It is a secondary effect for baroclinic highs

Physical Processes Affecting the Development of Pressure Systems

- Summary of Cyclogenesis/Anticyclogenesis Influences
  - Cyclogenesis contributors
    - PVA at 500 mb (indicative of divergence aloft and convergence at the surface)
    - Locally concentrated warm advection in the lower troposphere
    - Weak static stability of lifted air
    - Abundant moisture with LCL elevations

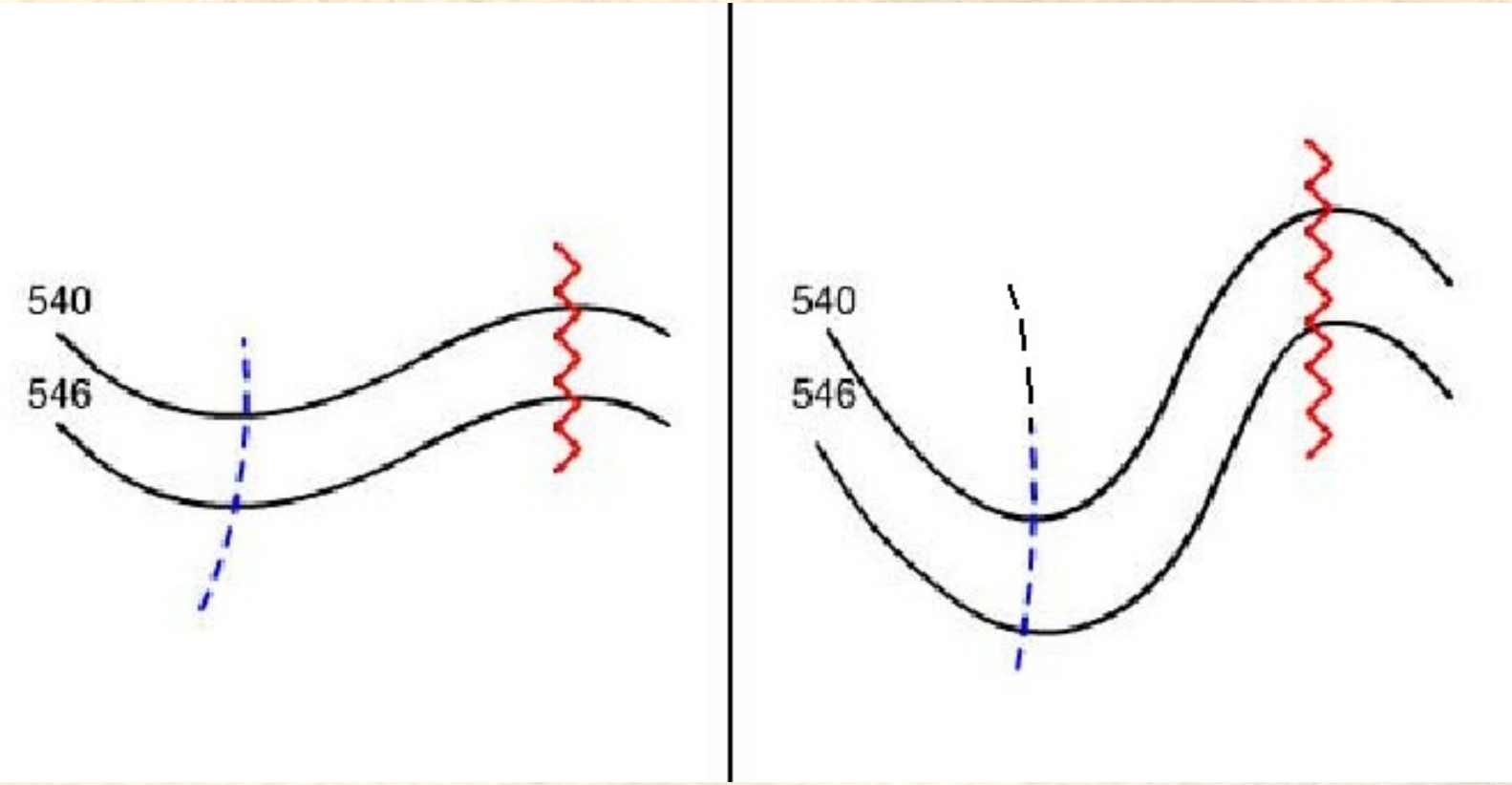
Physical Processes Affecting the Development of Pressure Systems

- Anticylogenesis contributors
  - NVA at 500 mb (indicative of convergence aloft and divergence at the surface)
  - Locally concentrated cold advection in the lower troposphere
  - Weak static stability of sinking (i.e. dry adiabatic subsidence)

Baroclinic Instability (Holton, 1992)

- Baroclinic instability is the process by which short waves amplify (increase amplitude with time) by extracting energy from north/south temperature gradient

Amplification of a Short Wave



Baroclinic Instability

- This is the primary mechanism responsible for development of mid-latitude synoptic scale systems (baroclinic lows and highs)
- It helps maintain global heat balance by transporting warm air northward and cold air southward

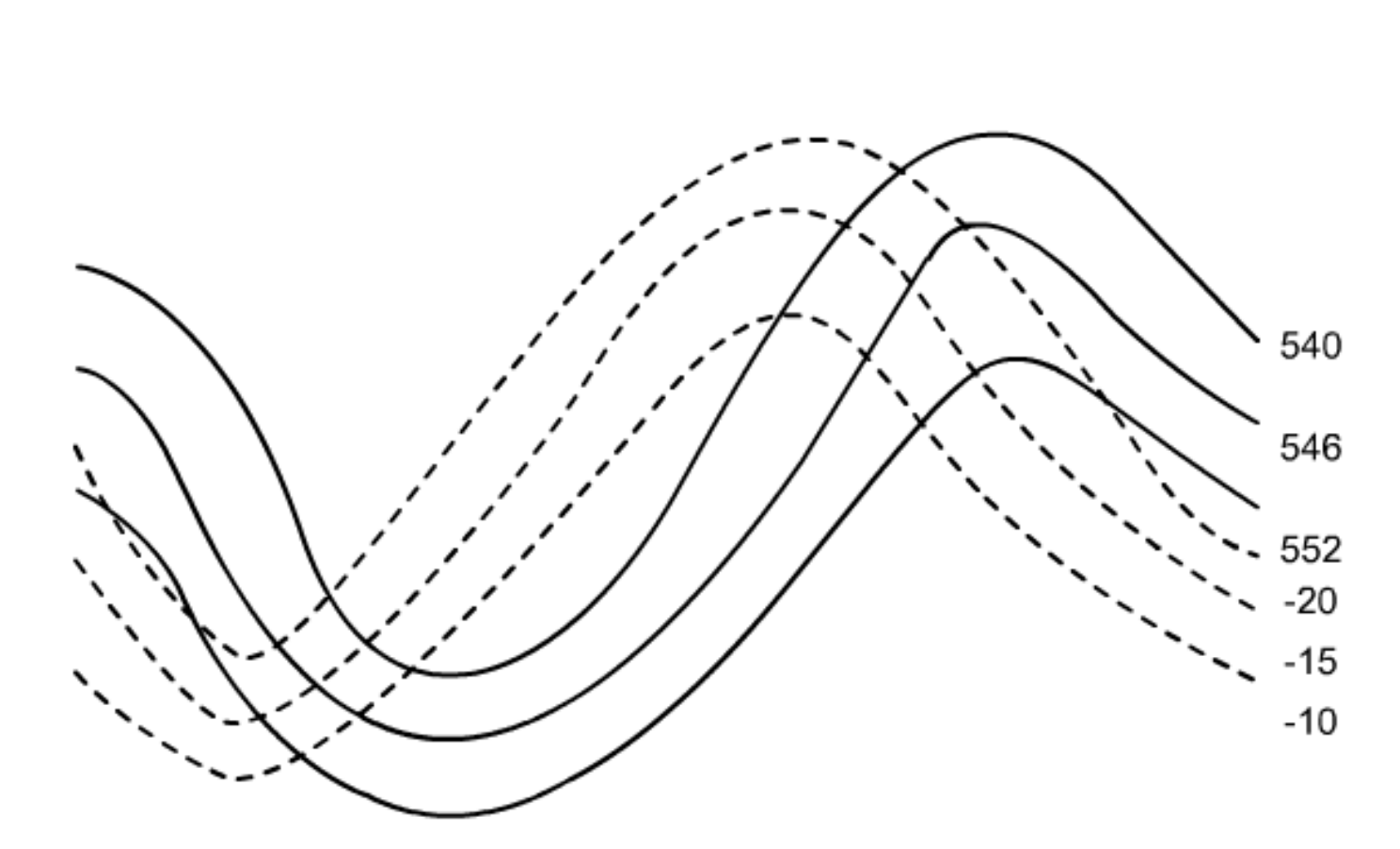
Baroclinic Instability

- Consequences of Baroclinic Instability Theory
  - Long waves are relatively stable
  - Major short waves are most likely to amplify due to baroclinic instability

Baroclinic Instability

- Development of systems through process of baroclinic instability
  - Tropical warming and polar cooling
    - This leads to strong north/south temperature gradient in mid-latitudes
    - Baroclinic systems use this temperature gradient as the source for potential energy conversion to kinetic energy.

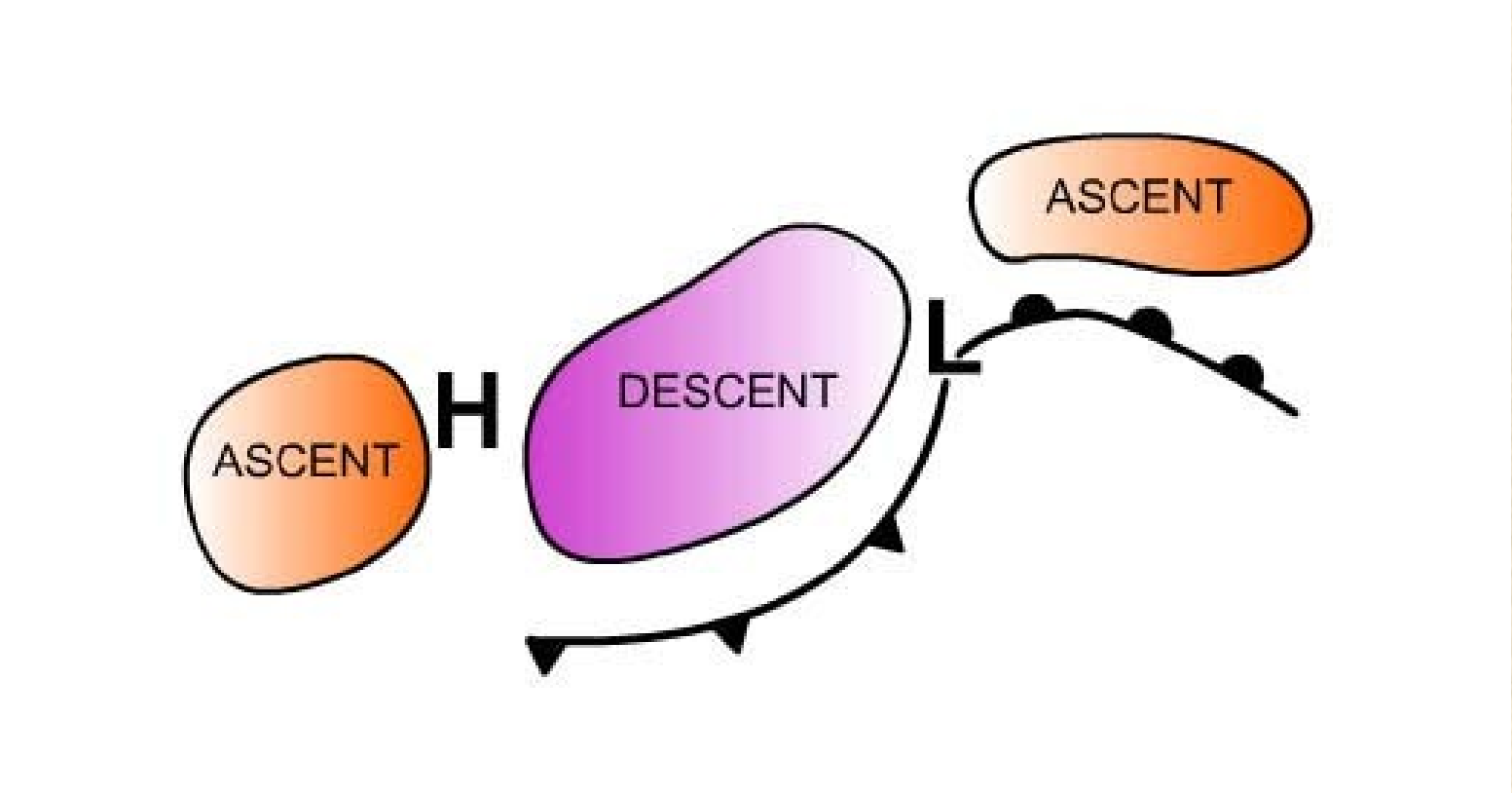
Thermal and Contour Troughs in a Major Short Wave



Baroclinic Instability

- Potential and kinetic energy is transferred to major short wave by thermal advection
  - Thermal advection causes upper-level ridges to build and trough deepen
  - Large energy transfer must occur for a major short wave to develop
    - Intense advection MUST be occurring throughout troposphere
    - There must be a well-developed baroclinic low and high to enhance advection in the lower troposphere.

Vertical Motions in Mid-Latitude Systems



Baroclinic Instability

- The temperature and height gradients represent a potential energy source which can be converted to kinetic energy in the short wave
  - Potential energy is converted to kinetic energy in order to develop the low-level circulation
  - Potential energy from the isobaric height pattern, is converted to kinetic energy as air accelerates across the height gradient from high to low heights.

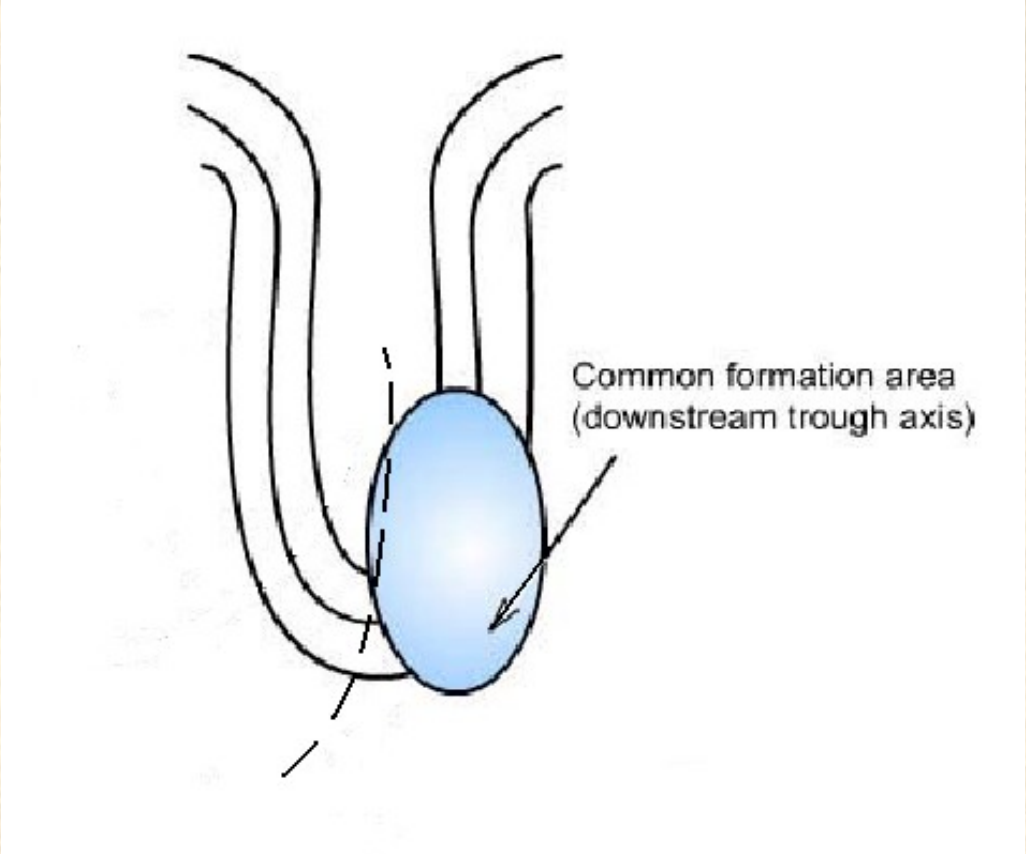
Baroclinic Instability

- This energy conversion process results from instability
  - As cyclogenesis/anticyclogenesis proceeds, thermal advection increases and more potential energy is converted to kinetic energy.
  - Increasing kinetic energy strengthens the low-level circulation
  - Process repeats and the system grows

Development of Baroclinic Lows

- Formation (initial conditions)
  - Cyclogenesis is favored by certain large-scale conditions
    - Long-wave pattern
      - Cyclogenesis typically occurs at and just downstream from a long-wave trough axes

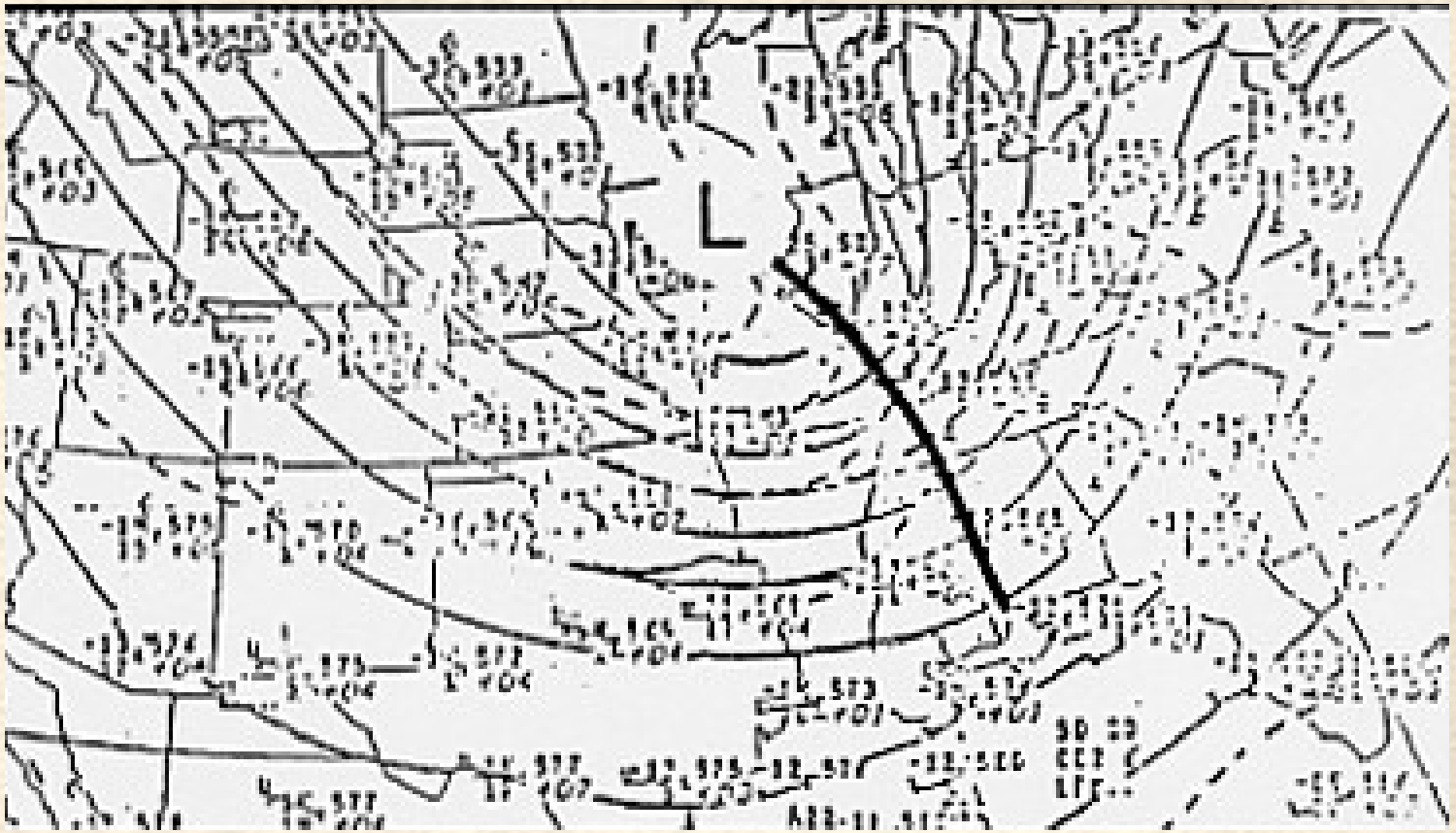
Favorable Area for Cyclogenesis in a Long-Wave Trough



Development of Baroclinic Lows

- Intense cyclogenesis normally occurs in troughs with a negative tilt (Sanders and Gyakum, 1980)
  - » Negatively tilted troughs are oriented northwest/southeast
  - » Negatively-tilted troughs are normally associated with enhanced diffluence, divergence, and thermal advection.

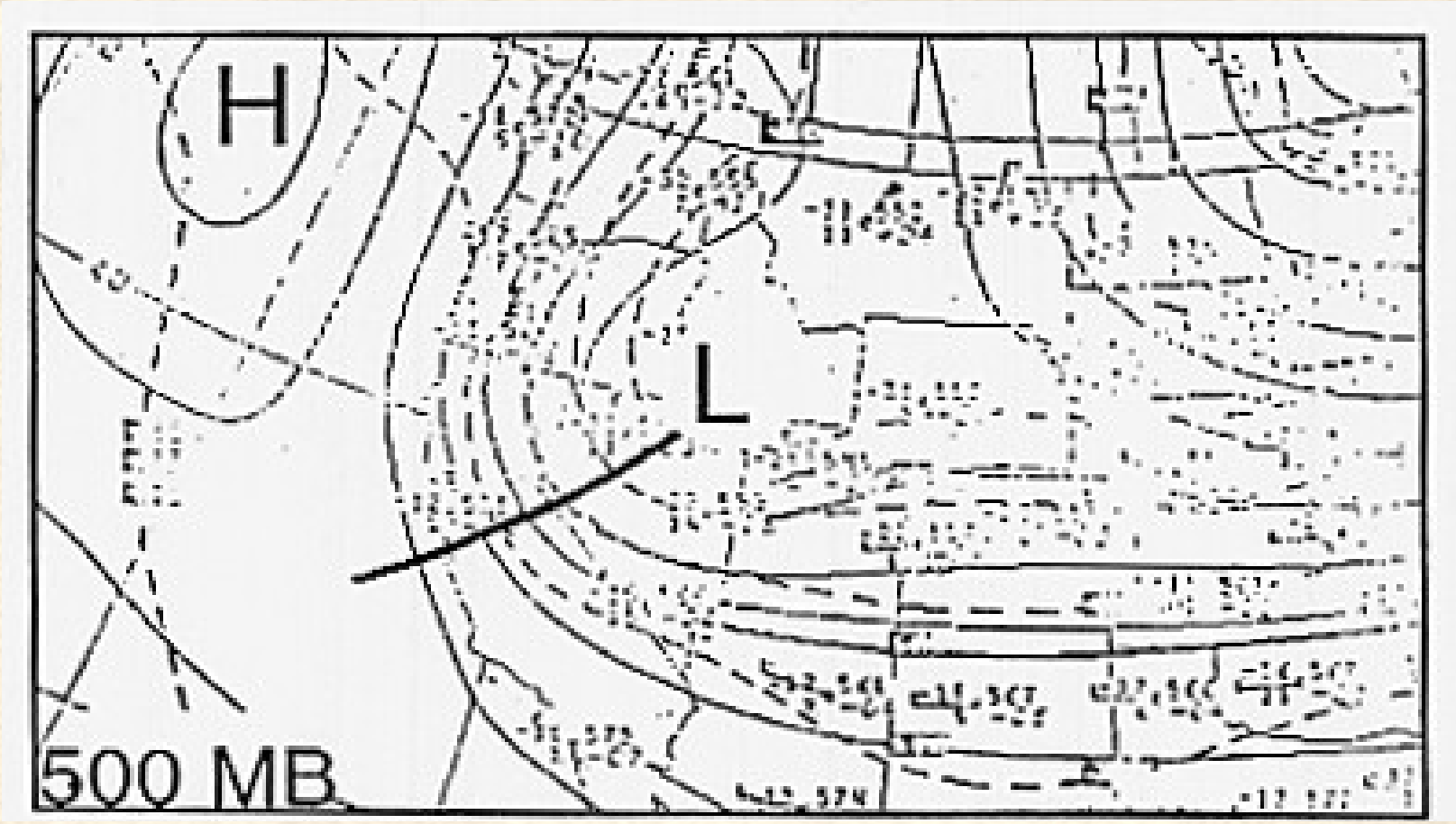
Negatively Tilted Trough



Development of Baroclinic Lows

- Weak cyclogenesis normally occurs in troughs with a positive tilt
  - » Positively tilted troughs are oriented northeast/southwest
  - » Positively-tilted troughs are normally associated with the suppression of diffluence, divergence, and thermal advection.

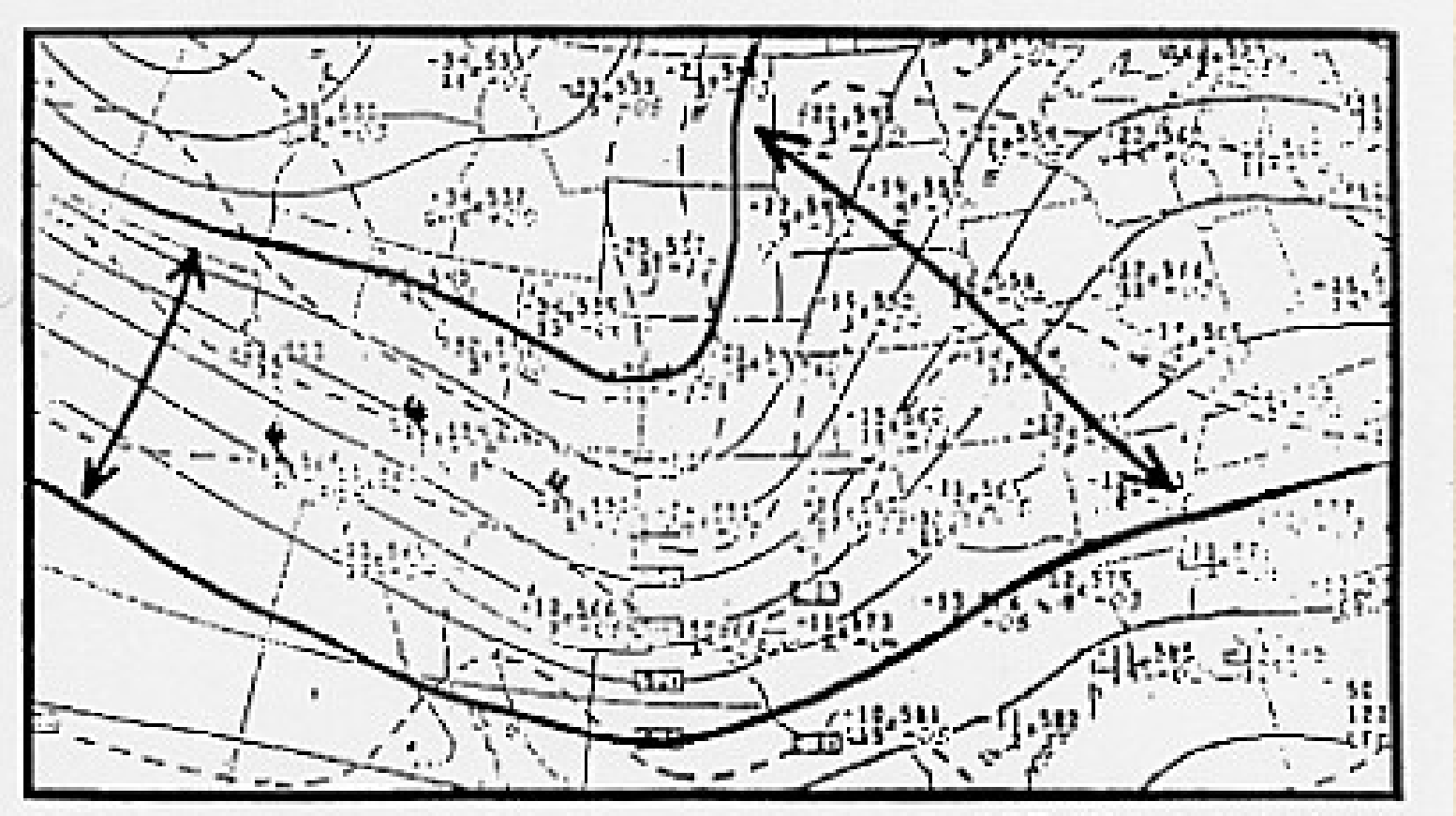
Positively Tilted Trough



Development of Baroclinic Lows

- Jet stream pattern
  - Cyclogenesis typically occurs under diffluent flow aloft. This difluence is many times indicative of divergence in the upper troposphere.
  - Upper level troughs often deepen when wind speeds upstream of the trough axis are greater than those downstream. Stronger equatorward-directed winds on the back-side of the trough often enhance cold advection into the trough axis, thereby amplifying the trough.
    - » The determination made based on contour spacing across trough axis
    - » Evaluate the overall change in contour spacing across trough axis

Diffluent Trough



Development of Baroclinic Lows

- Short waves
  - Baroclinic lows at surface is supported by upper-level short-wave troughs
  - Baroclinic instability transfers energy from the westerlies and accompanying temperature gradient into kinetic energy of the developing cyclone.

Development of Baroclinic Lows

- Generally, if there is no major short wave, then there will be no significant surface cyclogenesis. Without a major short wave, there will be a lack of:
  - » A jet streak (i.e. jet max)
  - » Divergence aloft
  - » Baroclinic instability

Development of Baroclinic Lows

- Low-level structure
  - » Baroclinic lows derive their energy from baroclinic instability
  - » The strongest temperature gradient occurs along polar front
  - » Strong baroclinic low form along the polar front

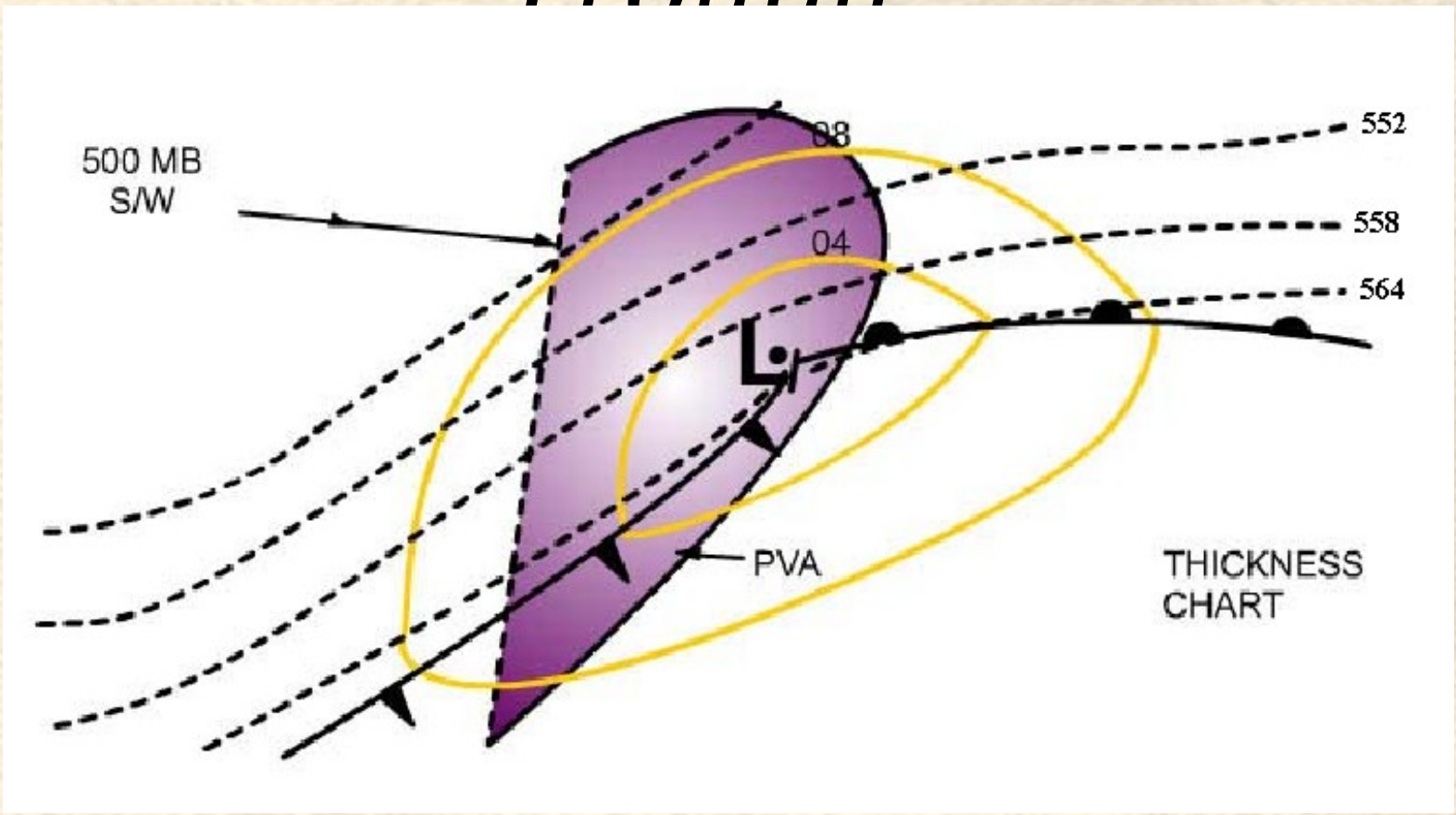
Development of Baroclinic Lows

- Petterssen's Rule:
  - Cyclogenesis will occur when and where an area of upper-level divergence (often indicated by PVA) becomes superimposed over a low-level frontal zone with weak thermal advection

Development of Baroclinic Lows

- This statement does not mean that PVA must reside directly above the surface front in order for cyclogenesis to occur. Often the PVA is superimposed over the frontal zone , but somewhat poleward or westward (I.e. toward lower thickness) of the surface front itself.

Surface Cyclogenesis Forced by a Short-wave Trough



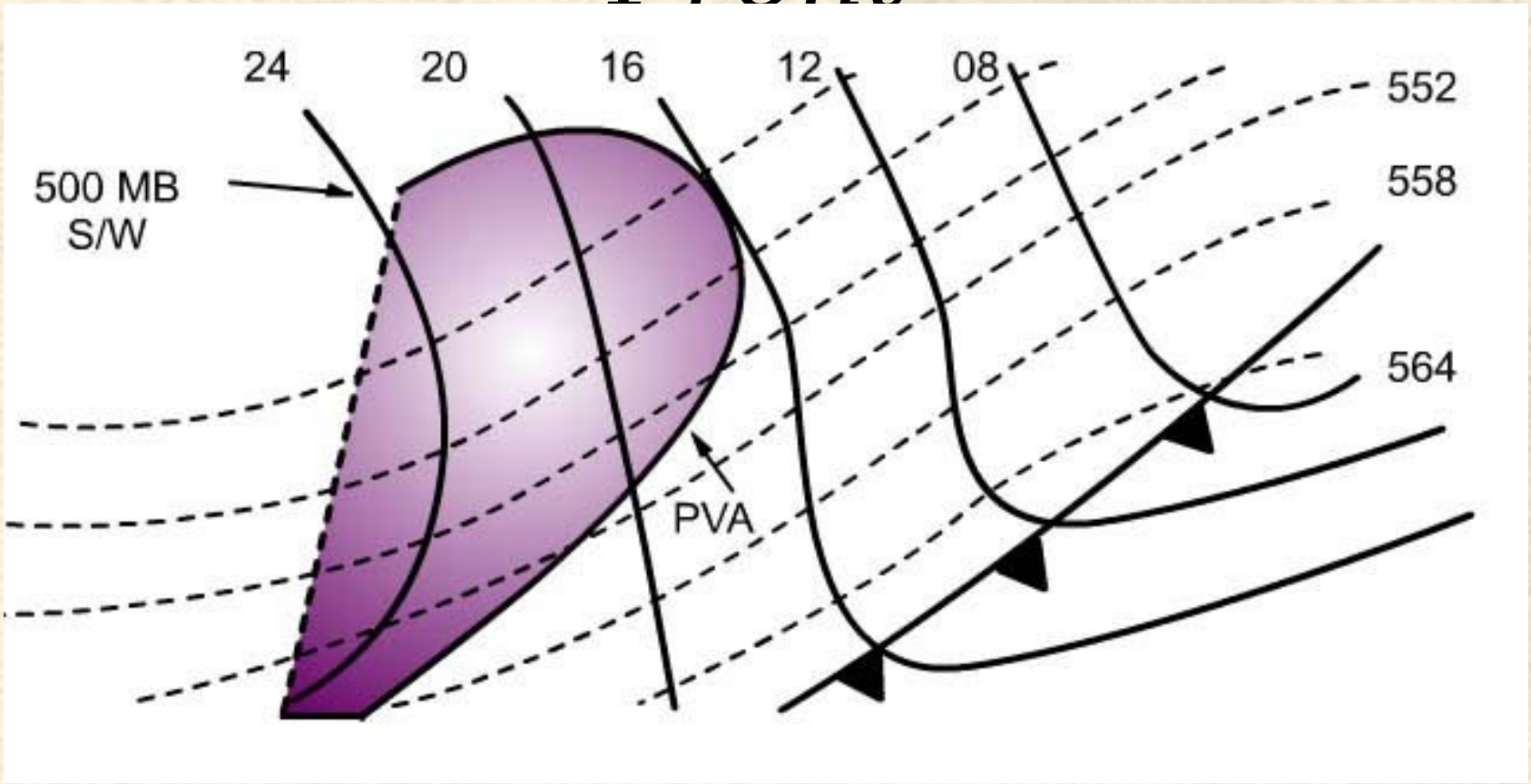
Development of Baroclinic Lows

- Petterssen's rule brings together all the mechanisms causing cyclogenesis
  - The jet stream, short-wave trough, and thermal field all must interact for rapid cyclogenesis to occur
  - If one of these features is missing, then a weak surface low may form, but development will be slow

Development of Baroclinic Lows

- Application of Petterssen's Rule
  - Only a few short waves cause development of strong baroclinic lows
  - A low may not form at all when the short-wave trough is well behind the cold front
    - » Divergence ahead of short-wave trough occurs behind surface cold front in region of CAA
    - » Pressure rises with CAA offset the pressure falls associated with divergence aloft

Short-wave Trough Well Behind a Surface Cold Front



Development of Baroclinic Lows

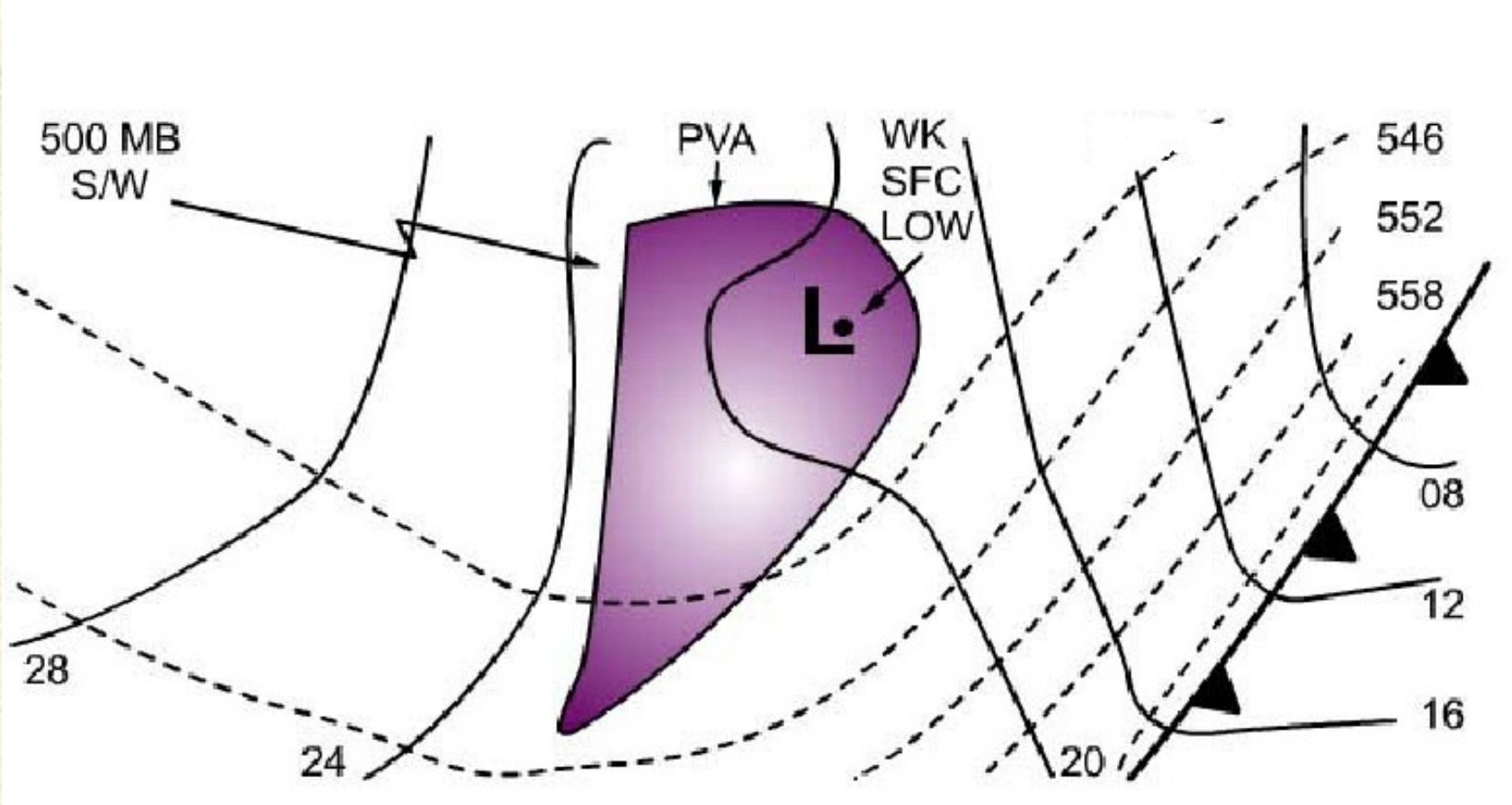
- Short-wave troughs moving over cold, and often dry, air masses
  - » Divergence ahead of the short-wave trough occurs over the cold air mass well behind the surface front
  - » Cyclone development at the surface cannot occur because there is no local increase in 1000-500 mb thickness.

Development of Baroclinic Lows

Divergence aloft promotes convergence and cyclogenesis at lower levels; however, cyclogenesis is often does not occur here because of off-setting effects in the colder surface air:

- » (1) Cold advection locally decreases thickness, thus opposing cyclogenesis.
- » (2) Lifting of stable, dry air produces rapid adiabatic cooling, resulting in a local decrease in thickness, and thus opposing cyclogenesis.

Short-wave Trough over Cold Air Mass



Development of Baroclinic Lows

- Often, only a surface trough will form in the cold air beneath the divergence aloft, but rarely will an actual cyclone develop within the cold air away from the surface front.
- However, if the cold surface air mass is shallow and the front displays only a gradual tilt with height, cyclongenesis may occur along the sloped frontal zone at levels above the surface (for instance, 850 mb), but not at the surface. Extensive “over-running” precipitation often is observed well behind the surface cold front in these situations.

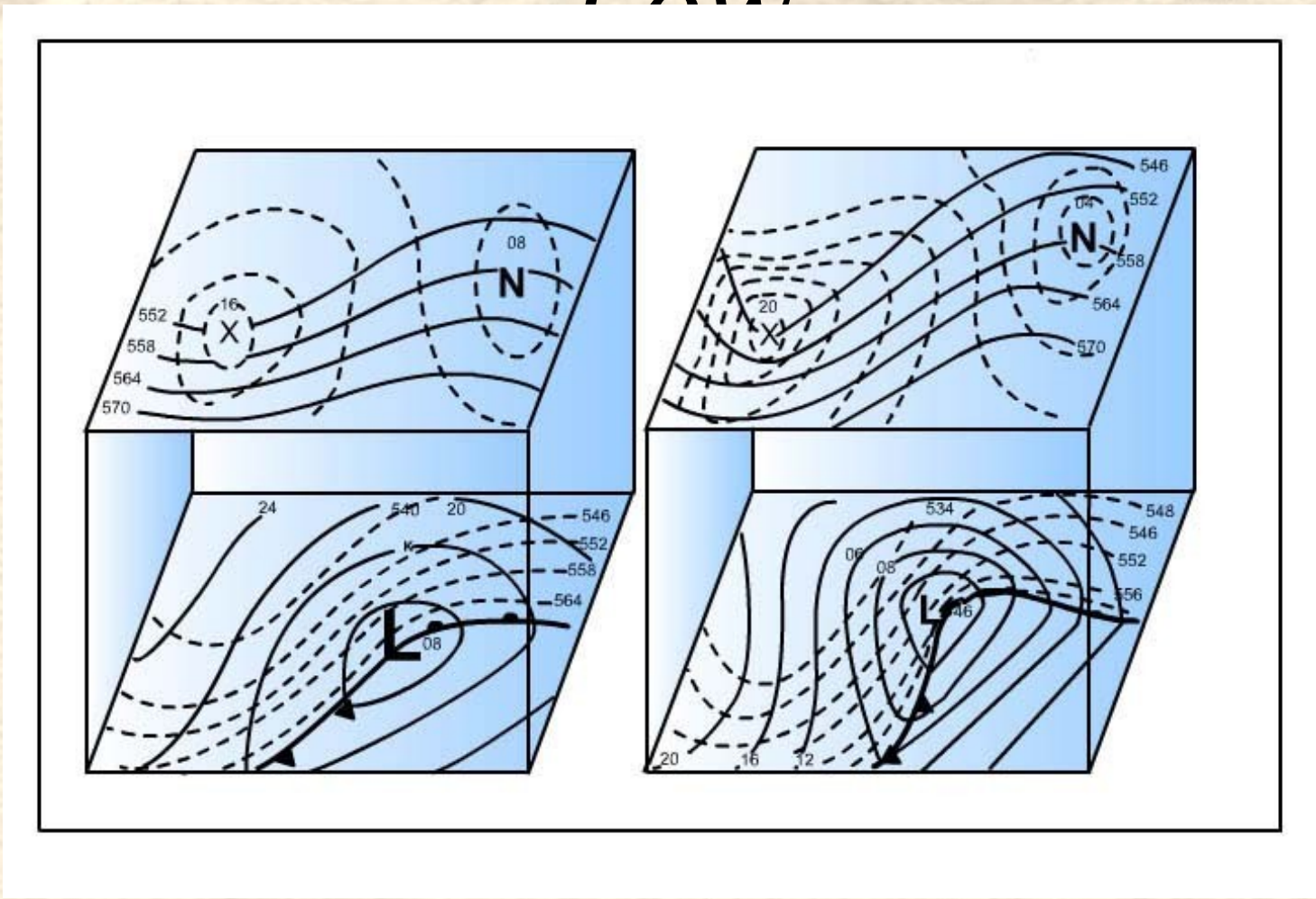
Development of Baroclinic Lows

- Intensification requires divergence and thermal advection to amplify the upper-level short wave
  - Most common along a slow moving cold front
    - » The temperature gradient will supply energy for development
    - » Cyclonic winds, already present across the front, represent a pre-existing cyclonic wind pattern (i.e., cyclonic vorticity) which will favor easy development

Development of Baroclinic Lows

- Upper-level conditions most favorable for intensification of short-wave troughs
  - » Strong surface cyclogenesis is associated with a rapidly intensifying short wave under divergent upper flow usually displaying a large amount of diffluence.
  - » Diffluent upper flow is common in negatively tilted troughs
  - » The short-wave trough intensifies as it moves into the long-wave trough position (i.e., wave phasing produces greater overall wave amplitude).

Developing Baroclinic Low



Development of Baroclinic Lows

- Intensification
  - Self-Development
    - Divergence aloft (often indicated by PVA) is superimposed near the baroclinic surface low. This divergence contributes to cyclogenesis
    - Cyclonic circulation strengthens the temperature advection around low
      - Stronger WAA builds major short-wave ridge
      - Stronger CAA deepens major short-wave trough

Development of Baroclinic Lows

- Building upper-level features (such as height gradient, wave amplitude, jet intensity, and vorticity) increases vorticity advection
  - Vorticity minimum in ridges becomes smaller
  - Vorticity maximum in trough becomes larger
  - Vorticity advection between the maximum and minimum becomes larger

Development of Baroclinic Lows

- Divergence ahead of short-wave trough strengthens
  - 1 Divergence between the trough and ridge is stronger
  - 2 Divergence causes surface low to deepen further and further cyclogenesis occurs

- This is called self-development because once development starts, it continues until some other influence acts to offset or stop it

Development of Baroclinic Lows

- Also remember: Local increases in the 1000-500 mb thickness near the cyclone promote cyclogenesis. As discussed in Physics, the hypsometric equation specifies that thickness is a function of the mean-layer virtual temperature. If virtual temperature increases in a layer, that layer's thickness will also increase.
  - Warm advection raises the virtual temperature.
  - Moisture advection raises the virtual temperature
  - Local diabatic heating and moistening of the air (i.e., local infusion of sensible and latent heat from warm and/or moist surfaces, etc…) raises the virtual temperature.

Development of Baroclinic Lows

- Braking Mechanisms
  - These are mechanisms, which slow down, and eventually stop development of baroclinic lows
  - Self-development initiates braking mechanisms
    - As the low intensifies, braking mechanisms begin opposing further development
    - These braking mechanisms will eventually offset self-development

Development of Baroclinic Lows

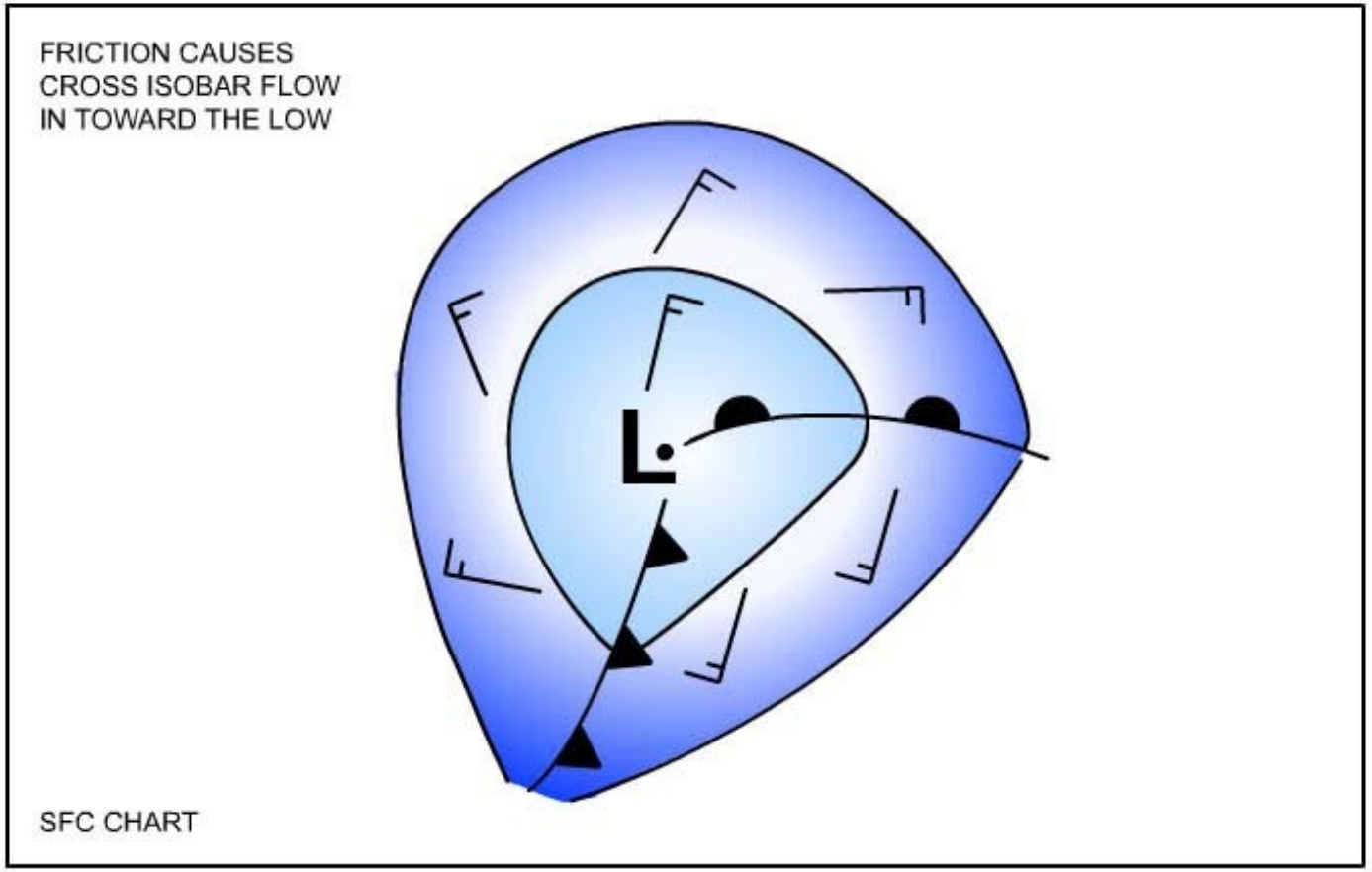
- Types of braking mechanisms
  - Boundary layer processes
    - » Low-level cyclonic circulation increases
    - » This increases the effect of friction, enhancing low-level convergence, partially offsetting the removal of mass aloft.

Development of Baroclinic Lows

- » Also, pressure falls in the low center produce an increase in the isallobaric wind which enhances surface convergence.

The isallobaric wind is an ageostrophic wind produced by pressure rises or falls as cyclones or anticyclones weaken or intensify.

Boundary Layer Convergence



Development of Baroclinic Lows

- Adiabatic processes
  - » Vertical motion increases as the low strengthens
  - » Adiabatic processes and stability determine strengthening

Development of Baroclinic Lows

» Lifting is a cooling process which locally reduces thickness and thus stifles cyclogenesis. The cyclone braking mechanism inherent in the lifting process can be reduced if:

(1) the lifted air is only slightly stable (I.e. warm, moist air is lifted as opposed to cold, dry air.

(2) The lifted air quickly reaches its LCL, thus promoting condensation and latent heat release (this implies an abundant moisture source for the developing cyclone). LCLs close to the ground are most important here because moisture is more abundant in the lower troposphere, implying a greater amount of latent heat release if this air is then lifted and quickly reaches its LCL.

Development of Baroclinic Lows

- Changes in structure of baroclinic low during development
  - Fronts
    - A baroclinic low developing along a front is called a frontal wave cyclone

Development of Baroclinic Lows

- Types of frontal wave cyclones:
  - Stable Wave (wave initiation)
    - » The amplitude of a baroclinic low does not change with time
    - » System may propagate, but does not change intensity.
    - » Sometimes the minor short-wave trough, providing support for the stable wave, is visible aloft.

Development of Baroclinic Lows

- The extent of clouds and weather is highly variable with such a system. Much depends on the abundance of moisture available to the system.
  - » (1) The shallow vertical slope of the frontal layer may allow an expansive region of clouds and precipitation between the surface front and the divergence (PVA) aloft, associated with warm advection over-running.
  - » (2) The weak cyclogenesis generally indicates weaker synoptic scale lifting with the system; this weaker lifting will possibly result in less precipitation and cloud cover.

Development of Baroclinic Lows

- Stable waves may evolve into unstable waves

Development of Baroclinic Lows

- Unstable Wave (wave intensification)
  - » The amplitude of a baroclinic low changes in time
  - » System deepens and undergoes cyclogenesis
  - » Both major short-wave troughs and waves on the front amplify with time as self-development occurs

Development of Baroclinic Lows

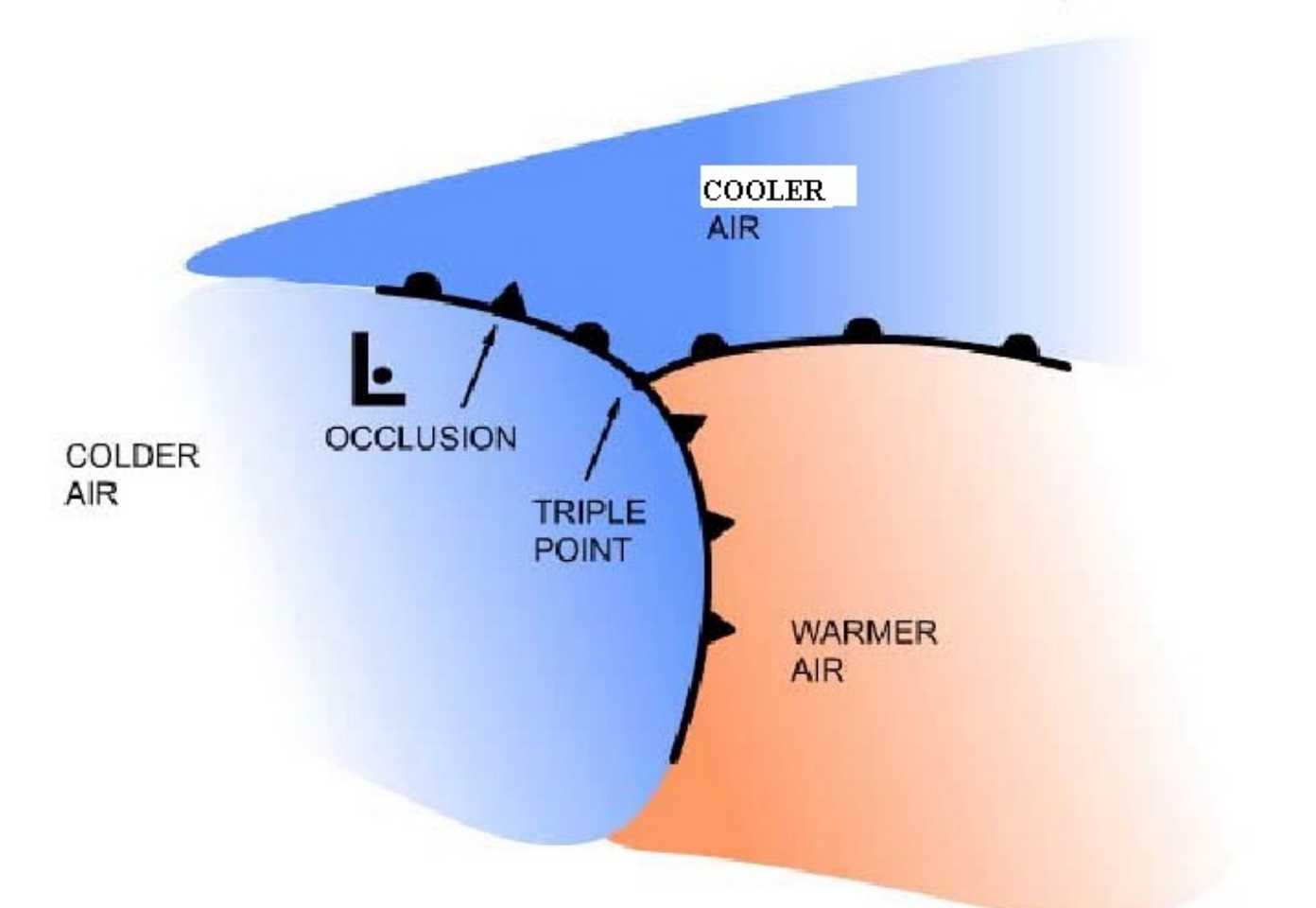
- Occluded fronts
  - » Unstable wave amplifies and moves to +n side (i.e., cold side) of jet
  - » Faster moving cold front appears to catch**es** up to warm front as the cyclone center moves toward lower thickness and farther into the colder air mass.
  - » It exhibits characteristics of both fronts

Development of Baroclinic Lows

» The point where cold, warm and occluded fronts meet is called the triple point

The triple point is favorable for new cyclone formation since it is located between the warm and cold advection patterns of the parent cyclone and is generally located in a surface region of pre-existing cyclonic vorticity and strong thermal contrast.

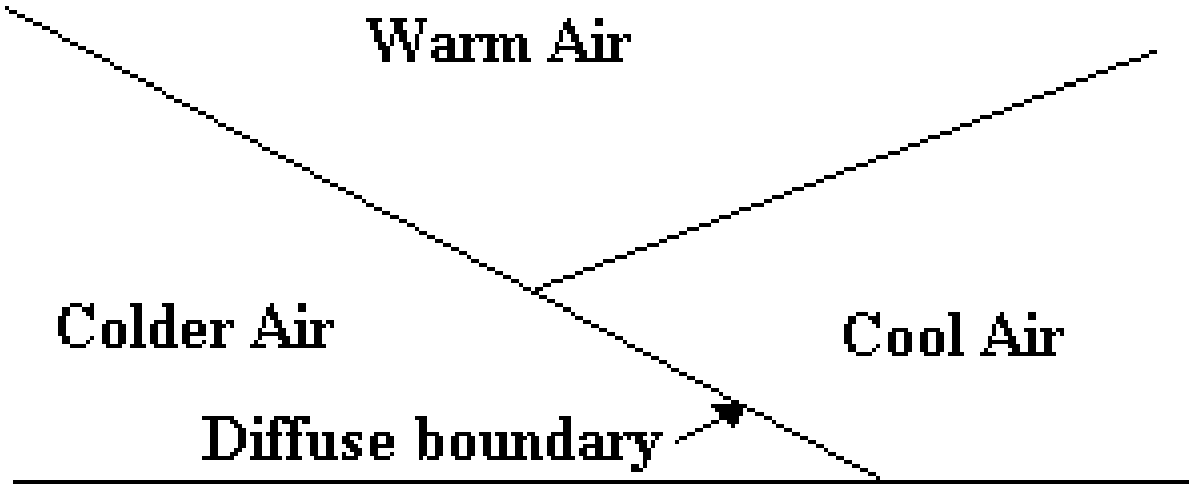
Occlusion



Development of Baroclinic Lows

- Characteristics of occlusions vary widely due to thermal structure modifications by vertical motion, topography, wind shear, precipitation, etc….
  - » Vertical structure
    - (1) The main frontal surface is aloft
    - (2) The tongue of warm air is aloft over polar air

Vertical Structure of an Occlusion



Development of Baroclinic Lows

» Horizontal

(1) Warm tongue will be reflected on thickness chart as a thermal ridge

(2) Thermal ridge axis corresponds to deepest warm air aloft

Development of Baroclinic Lows

- Dissipation
  - The low can lose its upper-level support
    - This can happen at any point in life cycle of low
    - Without upper-level support, low will fill

Development of Baroclinic Lows

- The low can proceed through its entire life cycle and become a cold equivalent barotropic low
  - It evolves from a frontal wave
  - It is vertically-stacked, deep, and slow moving
  - It fills slowly from bottom up
    - Boundary layer convergence adds mass to the column
    - Adiabatic cooling of rising air causes the thickness to decrease, so the upper low remains and is situated in cold pocket

Development of Baroclinic Lows

- Summary of the process
  - Initial Conditions
    - A baroclinic zone is located downstream of a long-wave trough (either slow moving front or thermal gradient)

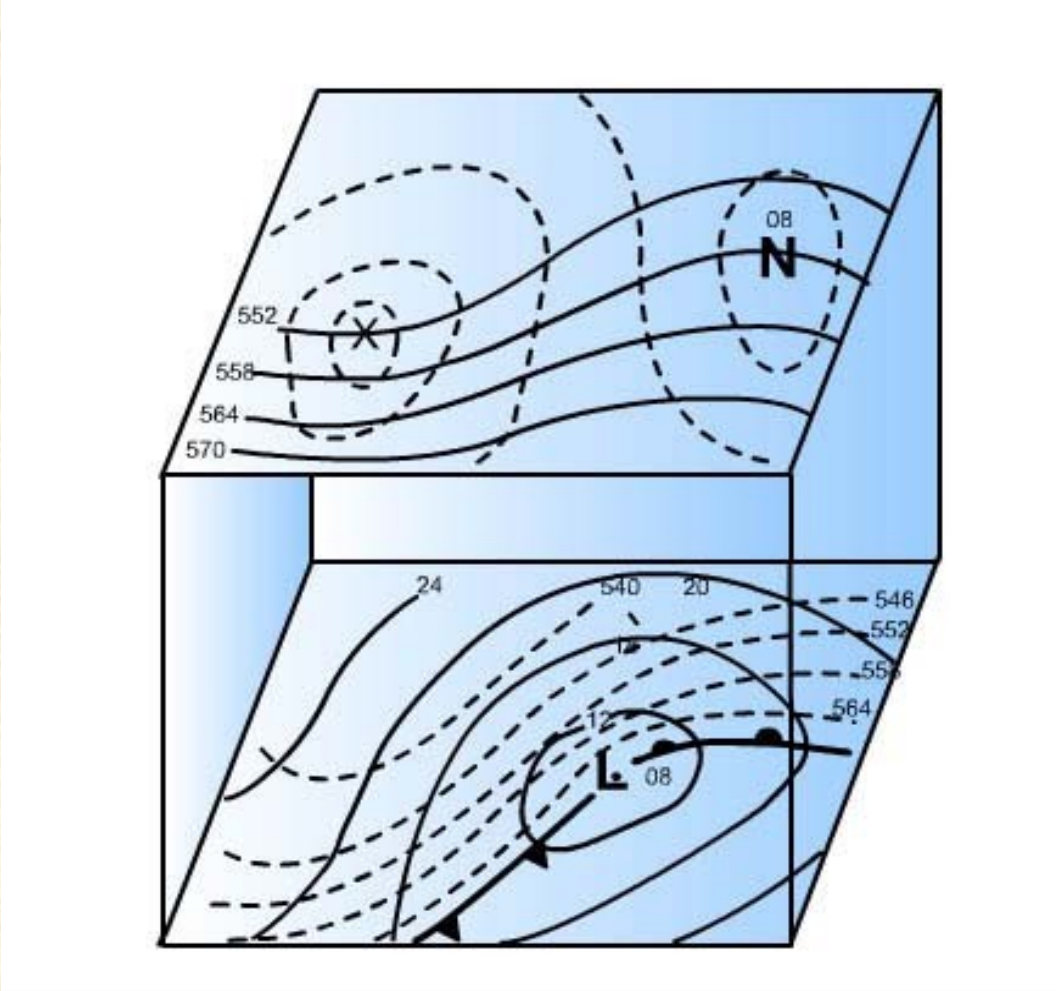
Development of Baroclinic Lows

- 500 mb/Vorticity
  - A short-wave trough approaches the baroclinic zone
  - Divergence aloft must be superimposed over baroclinic zone before development starts
- Surface/Thickness
  - Baroclinic zone/front separates the cold air from the warm air
  - Fronts are usually stationary or slow moving

Development of Baroclinic Lows

- Wave Initiation
  - The upper-level short-wave trough causes a wave to form along the front

Wave Initiation



Development of Baroclinic Lows

- 500 mb/Vorticity
  - The short-wave trough nears the surface front
  - Divergence aloft, ahead of short-wave trough, starts to occur near surface front

Development of Baroclinic Lows

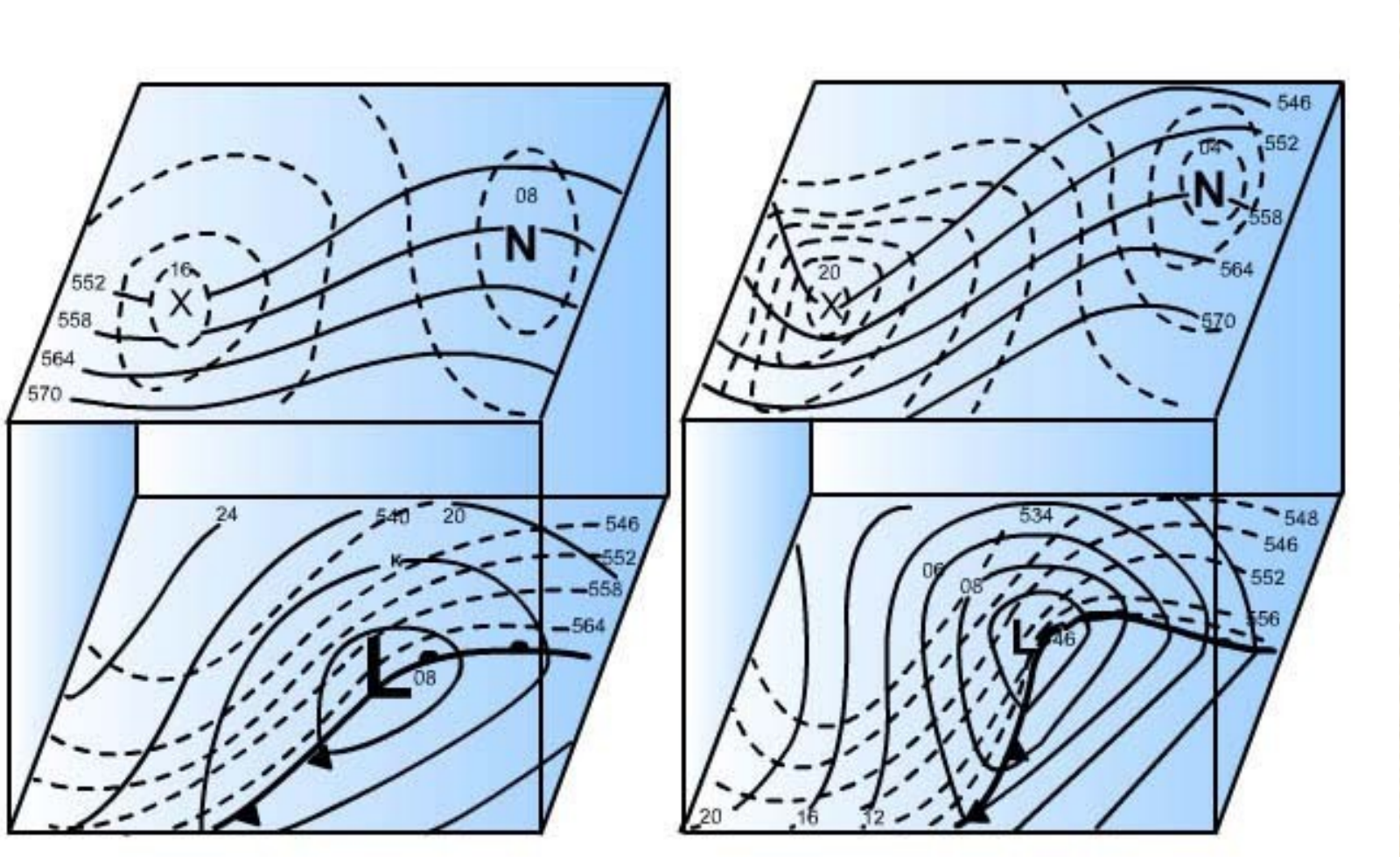
- Surface/Thickness
  - A wave develops along the front
  - Indications of wave formation
    - » Winds on either side of the front turn inward toward front. Often, this inward turn is most pronounced on the cold side of the front.

      This inward turning often is in response to falling pressure near the developing cyclone and surface convergence is increased.
    - » Precipitation in region will increase
    - » Satellite imagery will show a widening of cloud band

Development of Baroclinic Lows

- Wave Intensification
  - Self-development occurs as frontal wave and upper-level short wave interact
  - 500 mb/Vorticity
    - Thermal advection causes the upper- level short-wave trough to "sharpen"
    - Vorticity maximum in base of trough strengthens through increased cyclonic curvature of the trough and strengthening of the cyclonic shear near the trough axis.

Wave Intensification



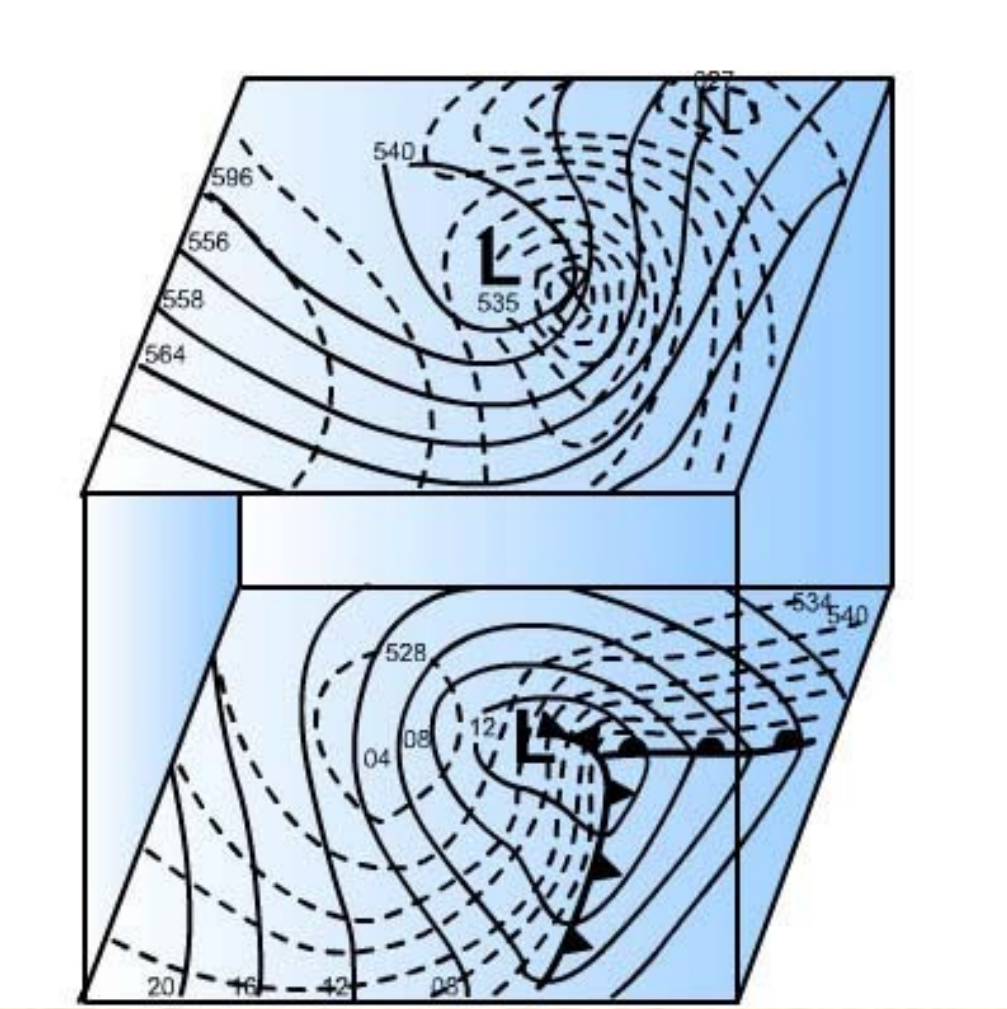
Development of Baroclinic Lows

- Surface/Thickness
  - Thermal advection pattern becomes significantly stronger.
  - Frontal wave is unstable and amplifies with time
  - Surface low is rapidly deepening
  - Cyclogenesis is aided by a local increase in 1000-500 mb thickness, generally ahead of the surface low.

Development of Baroclinic Lows

- Mature Wave
  - As self-development continues to occur, wave reaches its maximum intensity
  - 500 mb/Vorticity
    - The short-wave trough begins to "close-off" at 500 mb
    - Vorticity maximum will reach peak intensity
    - PVA is intense at the beginning, but weakens rapidly as vorticity maximum becomes coincident with closing low at 500 mb and the vorticity and height contours become more parallel to one another.

Mature Wave



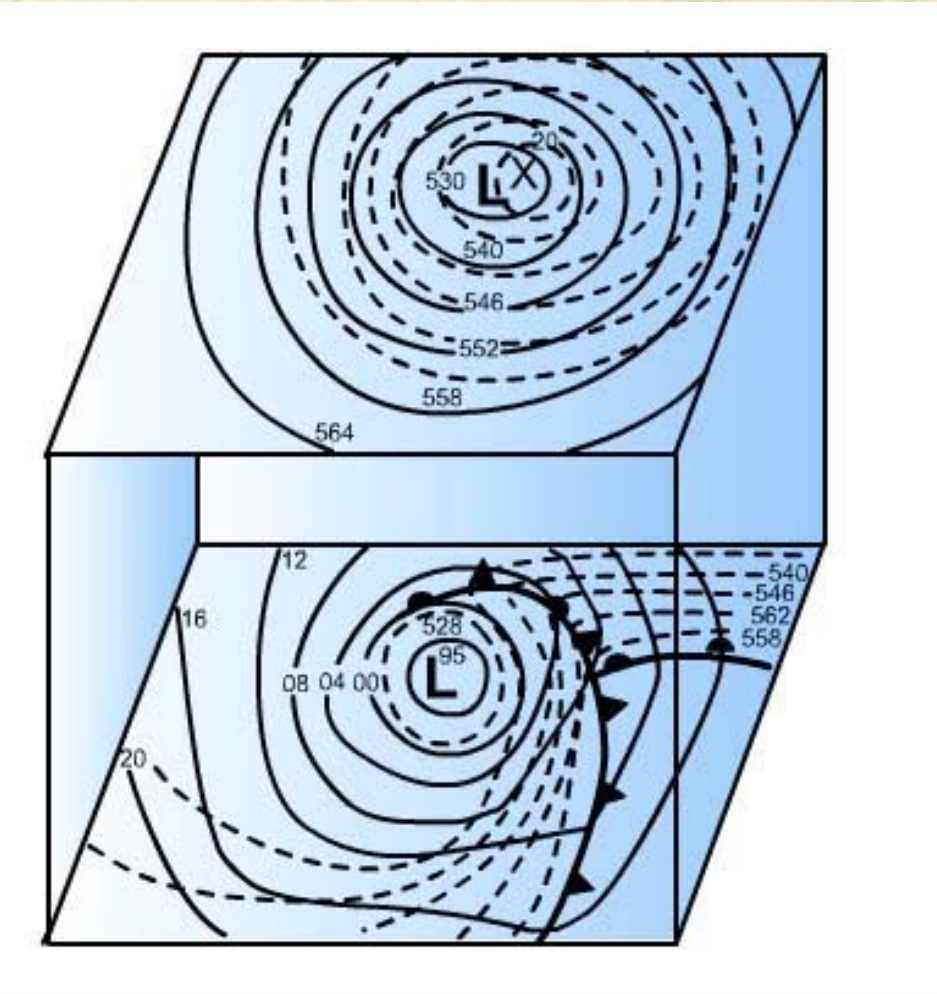
Development of Baroclinic Lows

- Surface/Thickness
  - 1 The surface low has occluded and reached peak intensity just after occlusion
  - 2 Vertical tilt between 500-mb low and surface low decreases, but system is not yet vertically stacked
  - 3 Thermal advection pattern has reached its peak development
  - 4 Surface low is removed from warm air mass

Development of Baroclinic Lows

- Dissipation
  - The system evolves into a cold equivalent-barotropic low
  - 500 mb/Vorticity
    - The 500-mb low develops more closed contours and becomes more circular and less wave shaped (e.g., the 500 mb low becomes more of a vortex than a wave)
    - Vorticity center is still strong, but is centered in 500-mb low where vorticity and height contours are essentially parallel.
    - Weak PVA signifies lack of upper-level divergence

Dissipation



Development of Baroclinic Lows

- Surface/Thickness
  - The surface low is beneath upper low as system is now vertically stacked
  - The surface low will fill and disappear long before upper low disappears
  - Surface low is well back in cold air mass and virtually removed from thermal gradient
  - Thermal advection pattern weakens dramatically as isobars and thickness contours become parallel or thickness gradient becomes well removed from cyclone location.
  - Occlusion has begun to separate itself from surface low

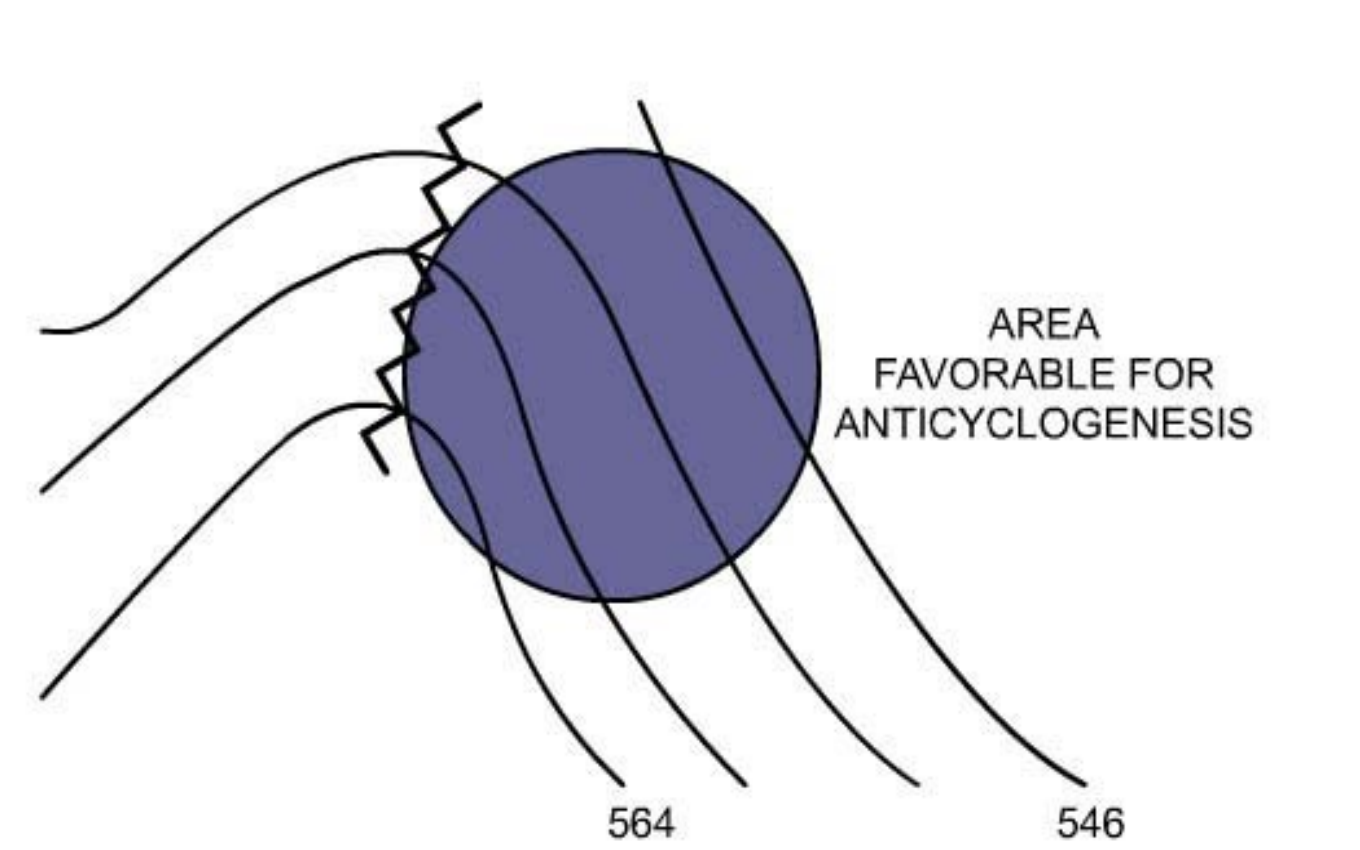
Development of Baroclinic Highs

- Formation
  - Anticyclogenesis is favored by certain large-scale conditions
    - Long-wave pattern - anticyclogenesis typically occurs at and just downstream from long-wave ridge axes

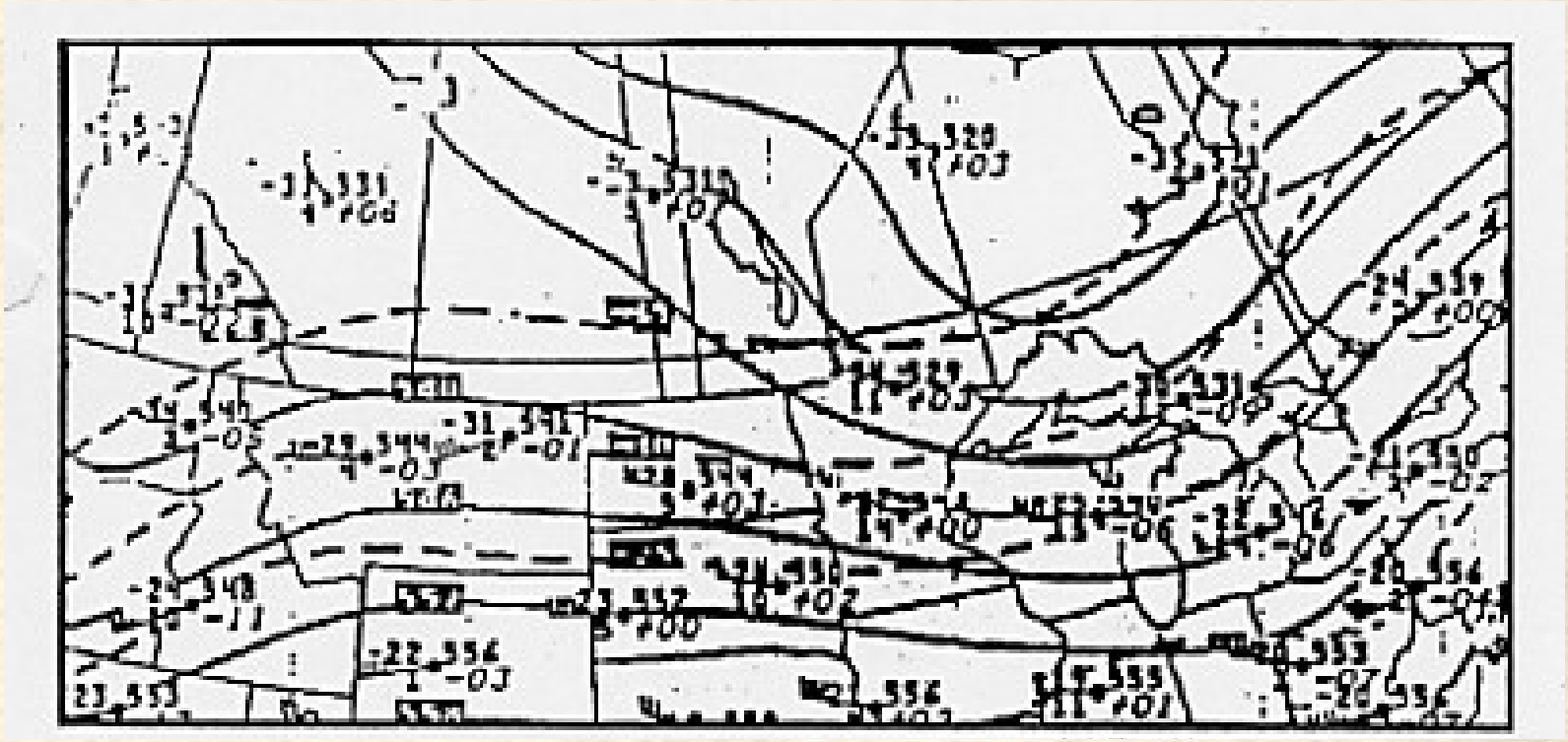
Development of Baroclinic Highs

- Jet-stream pattern - Anticyclogenesis typically occurs under confluent flow aloft, often indicative of convergence aloft.
  - For this reason, anticyclogenesis is common just downstream from confluent upper-level flow
  - The gradient wind relationship also promotes speed convergence aloft between supergeostrophic wind in the upstream ridge and subgeostrophic wind in the downstream trough.

Area favorable for Anticyclogenesis



Confluent Flow



Development of Baroclinic Highs

- Short waves
  - Upper-level short-wave ridges support baroclinic highs at the surface
  - Self-development depends on presence of upper-level ridge
  - In general, vigorous anticyclogenesis will not occur without a major short-wave ridge to support surface high

Development of Baroclinic Highs

- Low-level structure
  - Baroclinic highs derive their energy from baroclinic instability of the north/south temperature gradient
  - The strongest temperature gradient occurs along the polar front
  - Strong baroclinic highs are associated with convergence aloft (often indicated by NVA) and divergence at the surface. Surface divergence destroys fronts (i.e., divergence is extremely frontolytic); thus highs **ARE NOT** found on fronts

Development of Baroclinic Highs

- Baroclinic highs form on the cold air side of fronts

Development of Baroclinic Highs

- Intensification
  - Self-development process
    - Self-development of baroclinic highs is complimentary to that for lows
    - Baroclinic highs tilt with height and stack from the upper-level short-wave ridge
    - Convergence over the surface high causes the high to build
    - Anticyclonic circulation strengthens the temperature advection around high

Development of Baroclinic Highs

- This pattern causes the short-wave ridge to build and the short-wave trough to deepen
  - Since the ridge becomes more anticyclonic, vorticity minimum in the ridge becomes even smaller
  - Since the trough becomes more cyclonically curved, vorticity maximum becomes even larger

Development of Baroclinic Highs

- Convergence ahead of short-wave ridge strengthens
  - NVA between ridge and downstream trough increases, indicating stronger convergence
  - Increased convergence causes anticyclogenesis to occur

Development of Baroclinic Highs

- The pattern continues as a positive feed back loop
- The limit on strength of the anticyclonic gradient wind impedes development of the high

Development of Baroclinic Highs

- Also remember: Local decreases in the 1000-500 mb thickness near the anticyclone promote anticyclogenesis. If virtual temperature decreases in a layer, that layer's thickness will also decrease.
  - Cold advection lowers the virtual temperature.
  - Dry air advection lowers the virtual temperature
  - Local diabatic cooling and drying of the air (i.e., local removal of sensible and latent heat from the air when it overlays a cold and/or dry surface, etc…) lowers the virtual temperature.

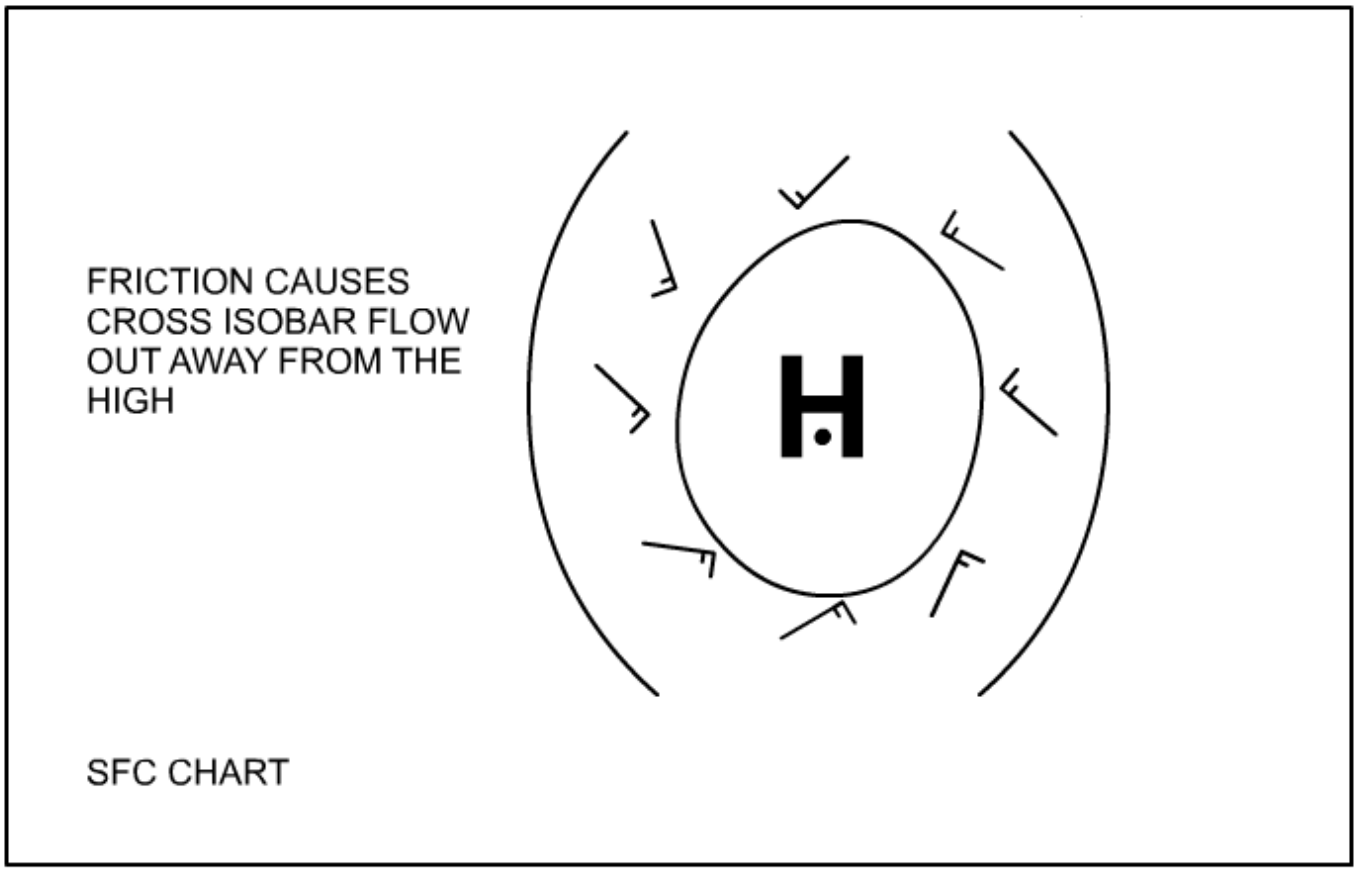
Development of Baroclinic Highs

- Braking Mechanisms
  - Mechanisms, which slow down and eventually, stop development of baroclinic highs
  - With development of high, other processes, called braking mechanisms begin
    - They eventually completely offset self-development process and prevent system from building indefinitely
    - Braking mechanisms for highs are much more efficient than for lows

Development of Baroclinic Highs

- Types of braking mechanisms
  - Boundary Layer Processes
    - » Anticyclonic circulation increases
    - » Low-level divergence increases due to increased frictional influence of the faster wind speed over ground. Also, pressure rises in the high center produce an isallobaric wind which enhances surface divergence.

Boundary Layer Divergence



Development of Baroclinic Highs

- Adiabatic Processes
  - » The vertical motion field intensifies
  - » Cold advection and convergence aloft force subsidence
  - » Subsidence virtually always occurs at dry adiabatic lapse rate, so latent heating via condensation is not a factor here (unlike in cyclones).
  - » The subsiding air warms dry-adiabatically; this compressional warming partially off-sets the cooling necessary to sustain the local decrease in thickness needed to promote continued anticyclogenesis.
  - » This helps limit**s** strength baroclinic high can attain

Development of Baroclinic Highs

- Changes in the structure of baroclinic highs during development
  - Air masses
    - Baroclinic highs form on cold air side of polar front
    - Early in life cycle, the high is associated with polar air mass, often in a polar source region where cold ground enhances the local decrease in thickness and promotes anticyclogenesis.
    - As high matures, tends to move southeast (assumes Northern Hemisphere), ultimately being absorbed into sub-tropical ridge

Development of Baroclinic Highs

- As the high moves out of its cold, often snow-covered source region, it moves over warmer ground or, worse yet, warm water, where local increases in temperature and moisture raise the thickness and promote anticyclolysis.

Development of Baroclinic Highs

- Jet stream
  - Normally form on +n side of PFJ
  - On occasion, a highs may move in other directions in response to changes in long-wave pattern
    - The high will move equatorward of PFJ while undergoing self-development
    - It will eventually become a warm core (i.e., subtropical) high

Development of Baroclinic Highs

- Baroclinic highs may weaken in one of two ways
  - Loss of upper level support
    - Upper-level convergence diminishes, or worse yet, divergence replaces the convergence aloft.
    - Without upper-level support, high will weaken

Development of Baroclinic Highs

- The high can go through entire life cycle and eventually be absorbed into sub-tropical ridges
  - As high moves equatorward, the center warms via subsidence and contact with warmer ground or water.
  - The equatorward movement of the anticyclone forces the vertical depth of the cold divergent air to become shallower, and thus more quickly modified..
  - As the temperature contrast decreases, the high will weaken
  - The high will eventually become a warm core high

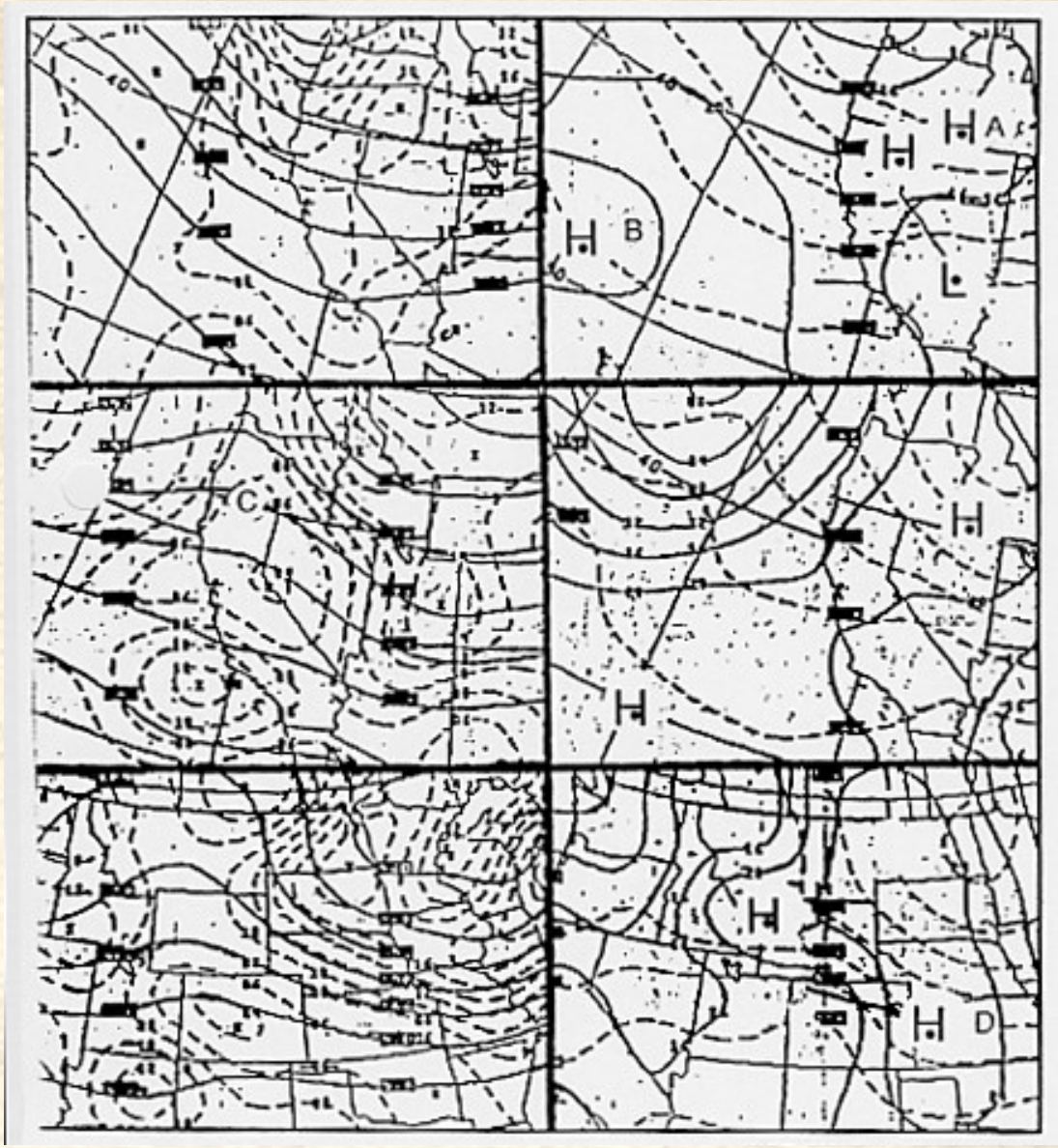
Development of Baroclinic Highs

- Summary of the process
  - Life Cycle of Classic Baroclinic High (Petterssen, 1956)
    - A classic baroclinic high develops
    - It will form as a “bubble” of high pressure, generally close to its high latitude source region.
    - The high intensifies beneath upper-level convergence ahead of short-wave ridge
    - It will normally move in an easterly or southeasterly direction (assumes Northern Hemisphere).

Development of Baroclinic Highs

- Eventually, air at center of high will warm due to subsidence and heating from below
- The high is eventually absorbed into subtropical ridge

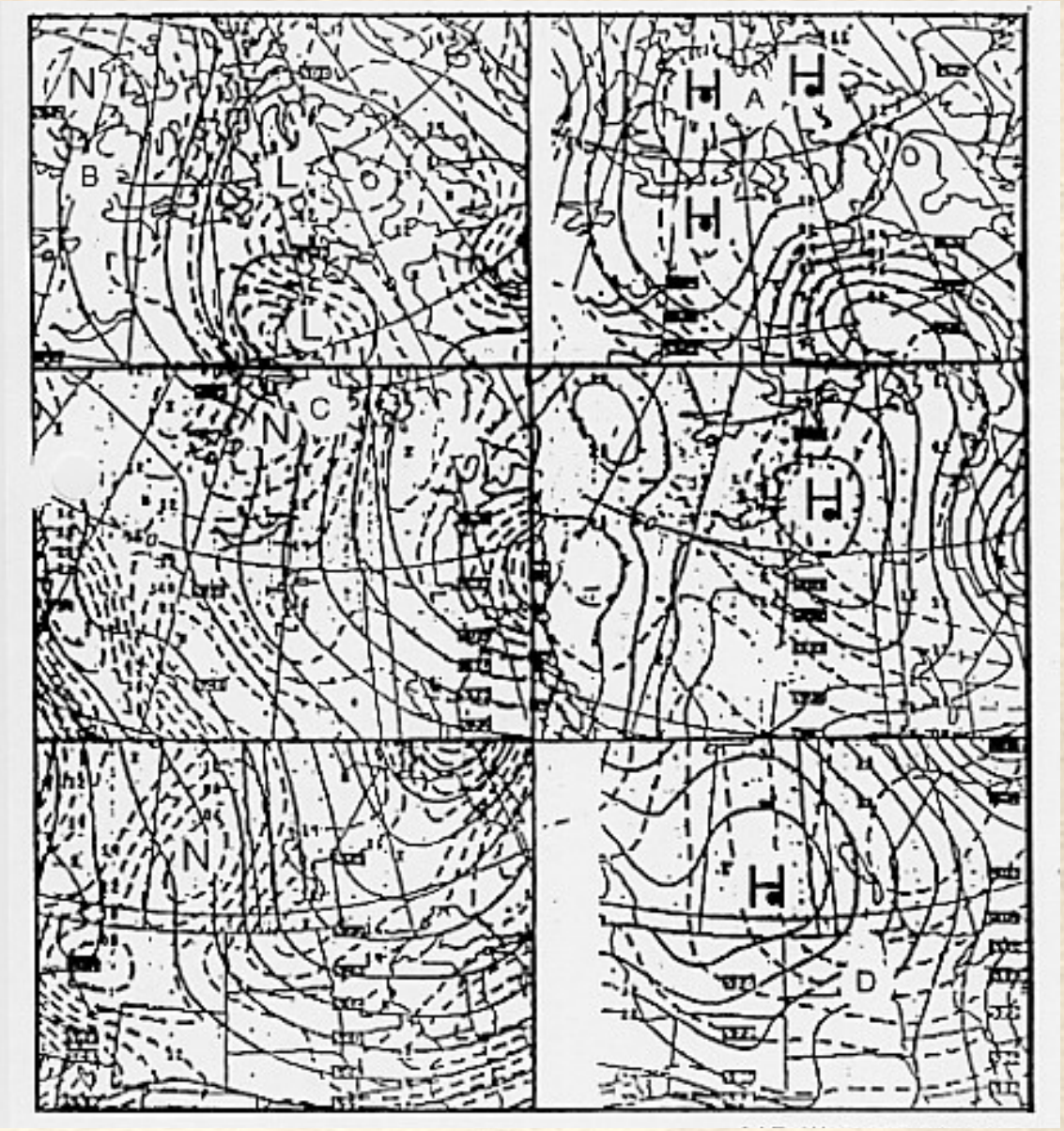
Development of the Classic Baroclinic High



Development of Baroclinic Highs

- Life cycle of polar (i.e., arctic) outbreak high
  - Polar or arctic outbreak high develops when a cold equivalent-barotropic (polar) high vertically stacked with its longwave blocking ridge in high latitudes, becomes a moving baroclinic system associated with a shortwave ridge.
  - Cold equivalent-barotropic high evolves into a baroclinic high east of a long-wave ridge
  - Short-wave ridge aloft supports the high
  - The high will move southeastward (Northern Hemisphere) creating strong cold-air advection to its east

Development Of A Polar (Arctic) Outbreak High



Development of Baroclinic Highs

- Eventually, air at center of high warms due to subsidence and heating from below
- The short-wave ridge weakens as it nears long-wave trough position and surface high loses support
- The high is eventually absorbed into subtropical ridge where it once again becomes equivalent-barotropic in nature.